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# THE IMPACT OF INTENSIVE APPLICATION OF PESTICIDES AND FERTILIZERS ON UNDERGROUND WATER RECHARGE AREAS WHICH MAY CONTRIBUTE TO DRINKING WATER SUPPLIES.
## A PRELIMINARY REVIEW

David Garrett, et al

Environmental Protection Agency
Washington, D. C.

11 December 1975

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A Preliminary Review

Office of Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

January 1976

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16. ABSTRACT

A report was submitted on an assessment of the impact of intensive application of pesticides and fertilizers on underground water recharge areas which may contribute to drinking water supplies and also a plan for developing additional information required to define the nature and extent of the impact of agricultural practices on groundwater supplies for public water systems, as required by the Safe Drinking Water Act (PL-93-523).

Both the assessment and the plan were subsumed under the four headings of nitrates, pesticides, economic impacts, and modeling and simulation.

Sources of groundwater pollutants were considered with a view towards determining their relative contribution to the overall problem. Special emphasis was placed on feedlot operation, a source of significant concern. Fertilizers, pesticides, and septic tanks were also examined, along with a detail examination of the nitrogen cycle. Economic impact of changes in agronomic practices were taken into account, and suggestions were made concerning the direction of future research efforts.

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Pesticides in Drinking Water
Fertilizers in Drinking Water
Groundwater as Drinking Water Supply

Nitrates in Groundwater
Nitrates in Drinking Water
Phosphates in Drinking Water
Phosphates in Groundwater
Feedlot Pollution of Groundwater
Septic Tank Pollution of Groundwater

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## A Preliminary Review

Office of Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

January 1976

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# PREFACE

This report is an initial technical review of some of the problems which may be posed by pesticides and fertilizers to drinking water supplies. Prepared for the Office of Toxic Substances by Ecosystems Incorporated, this final version incorporates some revisions made by the Special Projects Branch of the Office of Toxic Substances under the guidance of David Garrett, Chief of that Branch.

This report has been reviewed by the Office of Toxic Substances, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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# THE IMPACT OF INTENSIVE APPLICATION OF PESTICIDES AND FERTILIZERS ON UNDERGROUND WATER RECHARGE AREAS WHICH MAY CONTRIBUTE TO DRINKING WATER SUPPLIES

## Section 1

## An Initial Assessment

### I. SUMMARY

This report presents an Assessment of the impact of intensive application of pesticides and fertilizers on underground water recharge areas which may contribute to drinking water supplies; and also presents a Plan for developing additional information required to define the nature and extent of the impact of agricultural practices on groundwater supplies for public water systems, as required by the Safe Drinking Water Act (PL-93-523).

In the perspective of what additional information is needed to determine the time extent of agricultural impacts on underground water recharge, the operation of feedlots represents a significant concern. Special emphasis is therefore placed on this subject. Feedlots, in addition to being a most concentrated source of potential pollution, may also offer the greatest range of choices for abatement, some of which might even be economically profitable.

Pesticides appear to offer only a marginal threat to groundwater because of their adsorptive properties on soil structure and/or their short-lived persistence. The exception to this statement might be where pesticides are improperly applied, or there exist sandy soils or thin soils overlaying fissured rocks. Groundwater recharge from streams and lakes polluted with pesticide-contaminated runoff has not been considered to fall within the scope of the present study even though such runoff originated from agricultural areas. Pesticide pollution from "home garden" applications may also represent a genuine problem in terms of use by unqualified persons and improper disposition of residues, containers and excess supplies, but is defined as being outside the scope of the present study.

Fertilizers are usually applied at rates designed to yield a maximum agronomic return for the quantities of fertilizers applied, but this is often done on a "rule of thumb" basis. The application rates, methods and associated tillage practices have generally been established without regard to groundwater quality. Surface water runoff considerations have usually been assigned a greater importance. More information is required as to how much nitrate is reaching groundwater because the total annual fertilizers requirement was applied in one or two heavy treatments, rather than lighter applications made several times during the growing season.

Septic tanks on farms present an insignificant source of pollution to groundwater as related to public drinking water supplies. However, the well water supply on that particular farm may be susceptible. Often the design, construction, or maintenance of a septic system or a water well has been inadequate to protect against contamination. On the other hand, cesspools are considered to have a higher pollution potential to groundwater because essentially raw sewage may move directly to the groundwaters.

Cesspool installations are now widely prohibited, however, and even though thousands are still in use, it is not deemed necessary to investigate this problem further.

There is a need for greater knowledge of the process of nitrification and denitrification in various soils and subsoils as a function of soil temperature, climate, and biochemistry. Such studies are needed for both animal waste applications, and for fertilizer and crop cover sources of nitrogen. With regard to possible changes in law dealing with agricultural practices to protect groundwater from toxification it is recognized that impacts on the farmer could be dominant. Not all these effects are expected to be detrimental; in fact, some changes may, in the long run, contribute to increased productivity of the land.

Consideration is given to the geologic, edaphic, climatologic, and hydrologic aspects of the problem. In addition, the economic impact of modification of agronomic practices is taken into account. It is to be hoped that the cost of abatement measures may be offset, at least in some instances, by the opportunity for waste recovery as fertilizer or fuel.

The findings of the studies on the intrusion of toxic substances into groundwater recharge areas, whether from nitrates or pesticides, ought to be modeled to provide predictions of future consequences as a result of the continued use of these substances. Modeling will also permit parameters to be varied so as to determine the application levels at which these substances would no longer toxify the groundwater.

The Plan for the future work consists of a series of tasks designed to fill the gaps in current knowledge of the degree--and by what mechanisms--groundwater becomes polluted from agricultural practices, and to provide information important for pollution abatement and control. The tasks are grouped under four major headings: (a) Nitrates; (b) Pesticides; (c) Economic Impacts; and (d) Modeling and Simulation. Under the heading of Nitrates, sub-tasks deal with feedlots, fertilizers, septic tanks and problems which relate to several nitrate sources.

## II. GROUNDWATER RECHARGE AND TOXIFICATION FROM AGRICULTURAL SOURCES

### A. Introduction and Overview

This report has been prepared to help identify program elements required to determine the nature and extent of the impact from agricultural practices on groundwater supplies to public water systems, as stated in the Safe Drinking Water Act (PL-93-523).

About 97 percent of the earth's fluid fresh water is groundwater. This groundwater is used as a water supply by about two-thirds of the people in the United States [62]. To preserve this most valuable natural resource, a national program of groundwater quality protection and restoration is a necessity. A major need in developing such a program is a definition of groundwater pollution problems and potential problems and the scope and significance of each. To determine the extent of these problems the Office of Research and Development of the U.S. Environmental Protection Agency has initiated a program to assess groundwater pollution problems throughout the United States. Studies have been completed for Arizona, California, Nevada, and Utah [26], the South Central States [62], the Northeastern States [86], and the Northwestern States [95]. The studies for the other regions of the country are at various stages of preparation. These reports will cover the Southeast States (report due March 1976), the Mid-West States (October 1976), East (March 1977), and Hawaii and Alaska (March 1977) [100].

Groundwater is a most important asset in this country in terms of its freshness, usefulness in quality, and in general, quantity. Even though groundwater comprises at least 95 percent of the nation's freshwater reserves, only about 20 percent of the total quantity of water now used in the United States is supplied from underground sources [94].

Groundwater collection into aquifers is a direct result of seepage of surface water through percolation, seepage through cracks in underlying rocks and through the natural infiltration from lakes and rivers. This same groundwater is brought up to the surface by wells for human, animal, and agricultural consumption, making groundwater and surface water integral parts of a single dynamic system in which the water continuously flows between the two levels of the system. The quality of the water changes continuously as a result of this interface.

Groundwater pollution usually takes place very slowly. This is due to the slow movement of the sub-surface water into the aquifer. It may take many years to pollute groundwater due to its slow movement. However, once groundwater is polluted it may take many many more years, even centuries, and enormous cost, to restore the quality of the water even after the source of the pollution is removed. It is cheaper and easier to prevent pollution in subsurface water than to remove it.

There are two basic problems with groundwater contaminations. The first is handling existing cases and the second is to prevent new occurrences. Groundwater pollution arises both from natural phenomena and as the result of careless and deliberate acts of man. Subsurface water pollution can be the result of excessive and uncontrolled fertilization, pesticides, industrial and animal wastes, irrigation, disposal of oil field brines and highway deicing salts, accidental spillage of hazardous and toxic materials, injection of contamination into wells for waste disposal, and other causes.

Groundwater quality is an important public concern because of its effect on the health of man and animals and on the growth of vegetation. A lowering of groundwater quality can change the pattern of living in a region because water usefulness has deteriorated. Poor water quality has caused towns to stop expanding and even languish. Feedlots have been obliged to be relocated when the water supply became unfit for animal consumption.

Man has also contributed to groundwater contamination by dumping urban, industrial, and agricultural wastes, and by polluting surface streams which recharge aquifers. He has created saline conditions in groundwater by means of oil wells and extensive irrigations. Although man's contribution to contamination is large, not all groundwater contamination is the result of man's activities. Some contamination results from minerals leaching from rock formations through which water percolates enroute to an aquifer.

## B. Types of Contaminants

Biological contamination of groundwater may occur when human or animal wastes enter an aquifer. Microorganisms present in the wastes may be carried by the groundwater into nearby water wells and may cause disease when ingested. Inorganic chemical contamination differs from biological contamination in several important ways. Most important are the indestructibility of some inorganic chemicals, the persistence of the pollution created by their presence, and the difficulty in their removal. Nitrates in groundwater from agricultural practices, for example, are of increasing concern. The U. S. Public Health Service has specified certain "maximum" concentrations for such substances in drinking water [93]. In arid regions, inorganic chemical contamination is of great concern to agricultural water users. Generally, the quality criteria most often applied relate to total salt concentration (total dissolved solids), chloride, sodium, boron, and bicarbonate. Water low in salts is usually the most desirable for irrigation, but sometimes only water containing several thousand milligrams per liter of salts is available. High evaporation rates and lack of adequate flushing may cause salt accumulation in the root zone with a resulting decrease in crop yields. Reuse and recycling of water for irrigation is a frequent source of salt buildup in both surface and groundwater [32].

Organic chemical contamination is most often caused by such substances as detergents, gasoline, oil, and phenolic compounds. Phosphate contained in detergents and chemical fertilizers may constitute a hazard if present in excessive concentrations in groundwater. Gasoline and other hydrocarbons often end up as groundwater contaminants because of leaking tanks, pipeline breaks, or spills at the land surface. The presence of minute concentrations of hydrocarbons may result in abandonment of wells because of objectionable odors and tastes. Frequently, chemical additives complicate the contamination pattern. Phenols present in oil refinery or chemical plant wastes are often found in groundwaters. The presence of this contaminant is generally recognized by its taste and odor, which can typically be detected at concentrations as low as 0.001 mg/l (the U. S. Public Health Service recommended limit for phenol in drinking water) [42].

## C. Movement of Waste Fluids

To understand the health and other hazards associated with groundwater contamination, some familiarity with the basic principles of movement of contaminants in a groundwater body is necessary. Groundwater can simply be described as water contained in the saturated pore spaces and fractures of hard rocks and sediments beneath the land surface. It usually does not exist in a static condition but is constantly in motion. The rate of groundwater movement is highly variable both vertically and horizontally, and may vary from meters per day to centimeters per day or less. For example, in fractured crystalline rock the movement might be on the order of tens of meters per day, whereas in unconsolidated material it might be a few centimeters per day.

The configuration and slope of the water table are important considerations in estimating the directions and rates of travel of wastes in the subsurface environment. Contaminants dumped in an area where the water table is practically level and where little movement of groundwater is occurring will tend to stay in place. However, low gradients can be associated with high aquifer transmissivities in a given area, and high gradients with low transmissivities are great, the pollutant can move rapidly in spite of a relatively flat water table.

The thickness and composition of the unsaturated zone overlying the saturated zone are also important factors. Especially in cases of biological contamination, a thick unsaturated zone of fine-grained soil can adsorb and filter much of the pollutants before they can be introduced into the groundwater body itself.

Once at the top of the water table, fluid wastes generally will enter the groundwater system with only minor mixing with native groundwater or will float (nitrates for instance) on top of the saturated zone. The contaminant will then move with the groundwater toward its ultimate discharge point, which commonly is a spring or a river. Frequently, however, groundwater flow patterns are modified because of pumping from nearby wells. In such cases, the hydraulic gradient or slope of the water table is toward such a well, and the contaminants converge upon the center of pumping and emerge in the well discharge. In most cases, this is how groundwater pollution is discovered.

Under natural conditions and in the absence of pumping, water-table aquifers in the more humid regions discharge groundwater continuously into a nearby surface-water body such as a lake or river. Thus, the groundwater is entering the lake or stream and the aquifer itself cannot be contaminated by wastes carried by the stream. When a well is put into operation in such an aquifer near a stream, however, groundwater levels are lowered and the hydraulic gradient between the well and river may be reversed, causing surface water to flow toward the well. If the stream is polluted, contaminated river water may thereby be induced to flow to the well.

According to the laws governing fluid movement in saturated material, the direction of groundwater flow will always be toward points where the total hydraulic head is lowest. In many parts of the Northwest, saline groundwater in deep aquifers is under high artesian heads, and it can be induced to move upward into freshwater aquifers where heads are lower. An example would be the situation in which two zones are interconnected through abandoned or improperly sealed wells.

## D. Control and Removal of Contaminants

Because of the generally slow rate of movement of groundwater, a pollutant may exist for years before the problem is discovered. Contaminating fluids of different densities do not always move with the main body of groundwater. They can float near the top of the saturated sediments or sink toward the bottom of the aquifer [95]. Thus, determination of the direction of flow and areal extent of a contaminated groundwater body can be complex, and can be accomplished only by a rather detailed and costly investigation.

Generally, the most common approach to dealing with contaminated groundwater is to eliminate the source of pollution as quickly as possible, which is not always feasible. Even if the source of pollution can be removed, the groundwater contamination problem still may not be eliminated because a polluted groundwater body normally moves and disperses slowly.

The degree of reduction in concentration of contaminants with time is related to such factors as the hydraulic properties of the aquifer and recharge conditions. Nevertheless, long after a source of pollution has been removed, it is not uncommon for the contaminated groundwater body to continue expanding in areal extent for many years and to travel significant distances before its hazardous effects are minimized. Few studies have been conducted to define the degree to which contaminants will attenuate with time and distance from the source. Some recent modeling investigations simulating variation of groundwater quality with time and distance are expected to assist in the prediction of contaminant movement.

Other approaches to the solution of groundwater contamination problems are containment or removal of the pollutant. Containment involves limiting the spread of the pollutant within an affected aquifer. Pumping from wells, installation of drains, excavation of affected soils, and artificial recharging are the most common methods used for containment or removal.

## E. Monitoring Groundwater Quality

Another aspect of groundwater contamination is the problem of monitoring chemical and biological quality. Several factors are responsible for this difficulty, including:

(a) The complex nature of aquifer systems and groundwater movement.

(b) The variety of potential contamination sources.

(c) The frequent lack of baseline data.

(d) The economics of establishing a monitoring system.

The complexity of hydrogeologic conditions was mentioned in previous paragraphs. In most cases it is necessary to define the extent, thickness, direction and rate of movement of the polluted body of groundwater. This requires test wells and often geophysical surveys. The groundwater quality at various depths below the surface must be determined. Chemical tracers may be introduced into the aquifer to study direction and rate of flow of the groundwater. Many wastes are of complex chemical composition, and combinations of different wastes may produce reactions necessitating extensive laboratory work and research to establish the source of pollution.

A significant problem in monitoring groundwater quality is the general lack of baseline data. Usually, no thought is given to a monitoring program until such time as a problem is detected, often too late to establish a meaningful program. Even where water quality baseline data are available, the information is of limited value because in the past many key constituents were not routinely analyzed [90]. This applies to many of the trace elements such as selenium, molybdenum, and cadmium, and such other toxic metals as lead and zinc.

Finally, the problem of economics influences the establishment of a monitoring program. Federal, state, and often county legislation have pointed to the need for increased surveillance of waste discharge movement. Yet, because of limited funds and personnel, a hazard must be quite severe before a polluter, enforcing agency, or water user assumes the economic burden of establishing a monitoring system.

Certainly the majority of small municipal water-supply companies lack both financing and personnel to establish monitoring programs routinely. Also, most state agencies do not have adequate financial resources for sufficient trained personnel to enforce effective procedures.

## F. Sources of Information

In determining the quality of groundwater to be used for public drinking water supplies, several sources of information have been used. Hydrologic, geologic, edaphic, climatic, chemical and agricultural data sources were found and utilized.

Information on the quantities of groundwater were obtained from the U. S. Geological Survey (Murray and Reeves, Circular 676). Here it is revealed that beneath the conterminous United States lie some 65 quadrillion gallons or 200 billion acre-feet of groundwater within a few thousand feet of the land surface, part of which is renewable upon use. About 69 billion gallons a day (77.3 million acre-feet a year) are derived from groundwater reservoirs. This rate, amounting to approximately 20 percent of the total withdrawal use of water in the nation excluding hydroelectric use, constitutes only a fraction of the development possible, and the resource is capable of a greatly enlarged role in national water supply [56].

Figure 1-II-1 shows the magnitude and distribution of groundwater utilization in the United States [94]. Although groundwater is a significant source of water supply throughout the country, predominant usage is in the western part, mainly for irrigation.

The nation's systems of groundwater reservoirs vary from

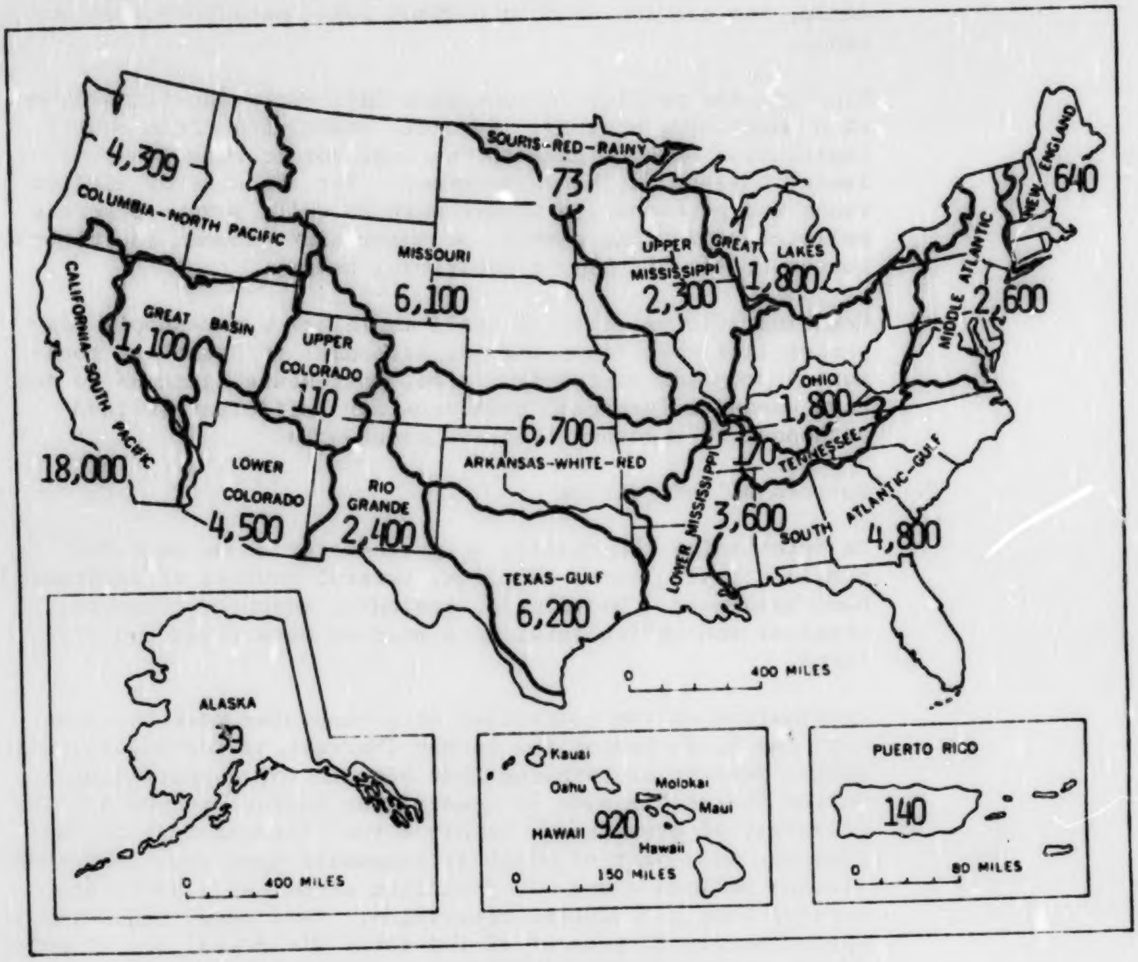

4,309
COLUMBIA-NORTH PACIFIC
SOURIS-RED-RAINY
73
NEW ENGLAND
640
MISSOURI
6,100
UPPER MISSISSIPPI
2,300
GREAT LAKES
1,800
MIDDLE ATLANTIC
2,600
CALIFORNIA-SOUTH PACIFIC
18,000
GREAT BASIN
1,100
UPPER COLORADO
110
OHIO
1,800
6,700
ARKANSAS-WHITE-RED
170
TENNESSEE
LOWER COLORADO
4,500
RIO GRANDE
2,400
LOWER MISSISSIPPI
3,600
SOUTH ATLANTIC-GULF
4,800
TEXAS-GULF
6,200
0
400 MILES
ALASKA
39
0
400 MILES
Kauai
Oahu
Molokai
Maui
HAWAII
920
Hawaii
0
150 MILES
PUERTO RICO
140
0
80 MILES

Figure 1-II-1

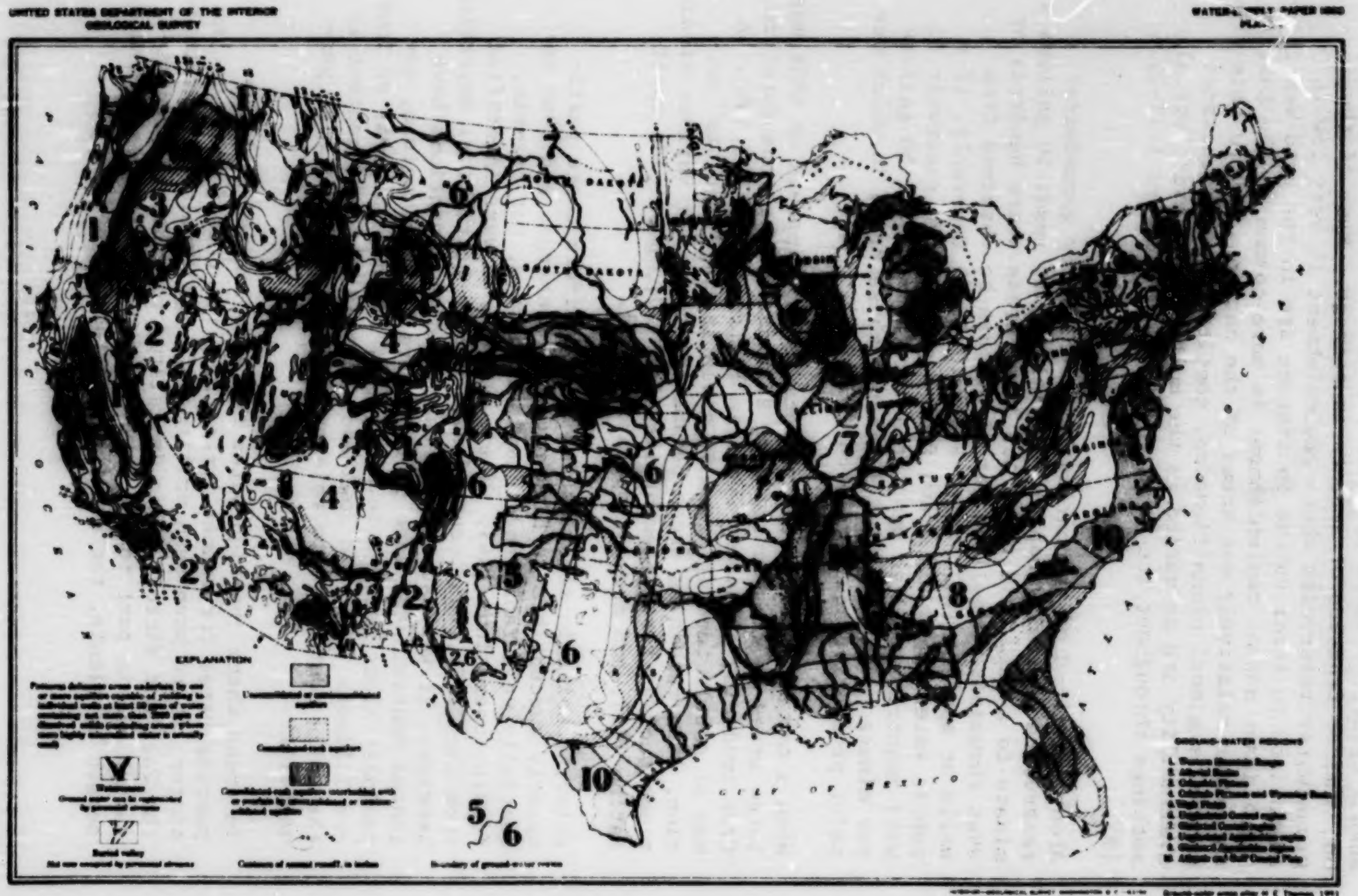
Groundwater withdrawn, by regions, 1970 in million gallons a day reservoirs that are drained and refilled naturally on an annual cycle, to those in which the annual replenishment is but a minor fraction of amounts in storage. Many of the groundwater reservoirs where replenishment is very low in comparison to total volume in storage are in the arid West; significant annual replenishment is more common in the East and other relatively wet areas of the nation. Beyond this general regional classification, conditions of groundwater availability are as varied as the multifarious hydrological settings throughout the country [94]. (See Figure 1-II-2) [85].

About one-third of the nation is underlain by groundwater reservoirs generally capable of yielding at least 50 gallons a minute to a well, and there are large areas where hundreds or even thousands of gallons per minute can be obtained from wells or springs [94]. (See Figure 1-II-2) Generally, if a public water supply is drawn from a groundwater reservoir it will require a well to pump at a rate of at least 50 gallons per minute. Figure 1-II-2 indicates those areas in which our major productive aquifers occur [94, 74].

When a map of agricultural regions is superimposed on this map large areas of the country were eliminated from consideration. Crop producing areas are shown in Figure 1-II-3 [73, 80]. A map of cattle feeding areas is given in the "Feedlots" section. The remaining areas became the focus for various situations such as fertilizer application [30], pesticide application [81], and feedlot operation [77].

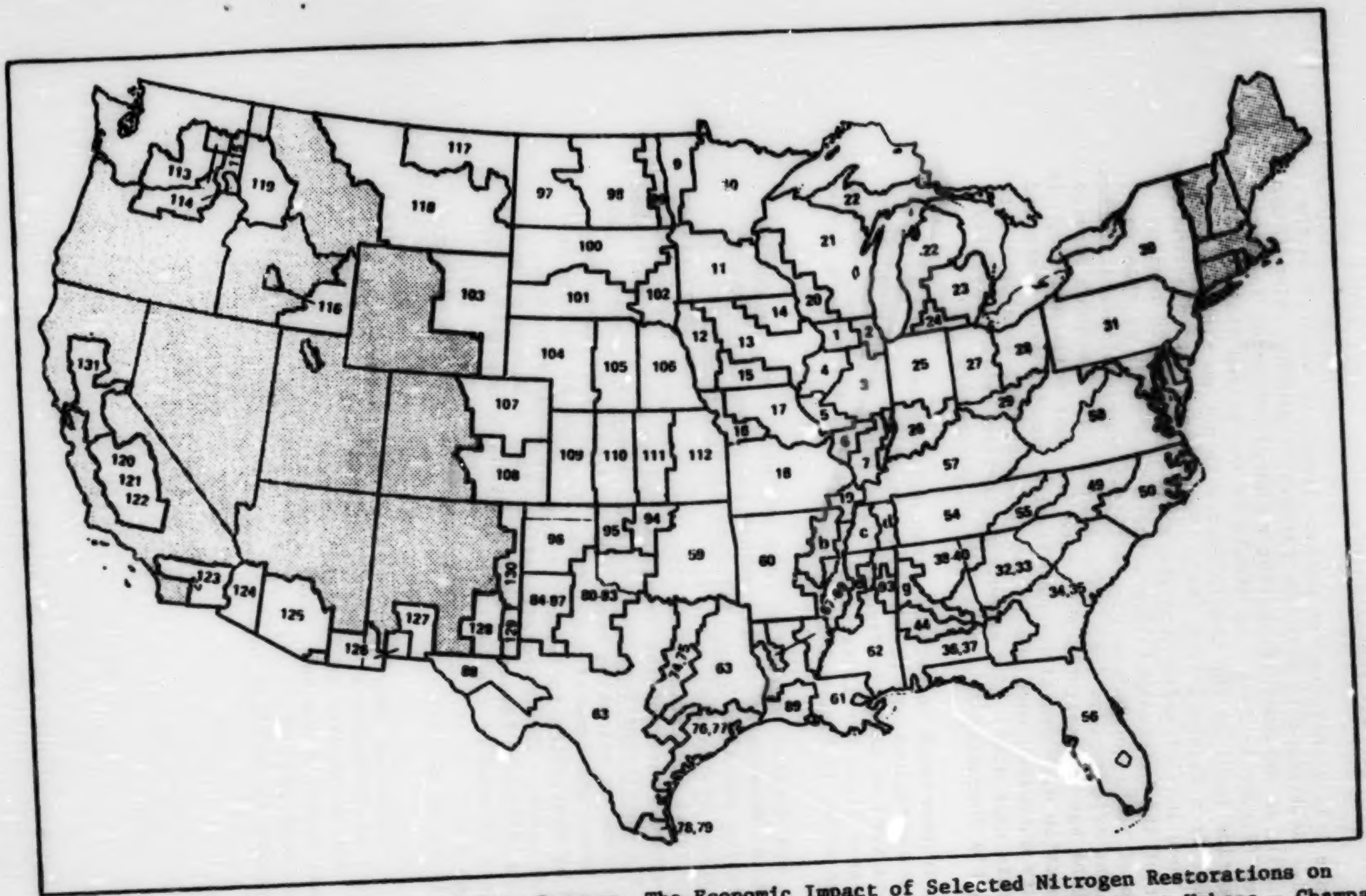
Alluvial soils in river basins make aquifers there particularly susceptible to high rates of recharge, and thus potentially vulnerable to contamination from, for example, feedlot operations [44]. These operations were identified from the U. S. Department of Agriculture Statistical Reporting Service. It was ascertained that feedlot operations have indeed contaminated some groundwaters in some regions, especially along the Platte River [44, 72] and in areas of Iowa and Illinois [88]. In Iowa and Illinois the sand content in the soils contribute to this problem due to their high permeability.

In areas where the high water table is lowered by heavy pumping rates for summer irrigation, but raised again in the winter, there have been problems of high levels of nitrate in the Fall and Winter. This is related to enhanced precipitation and in part to the lower demand for nitrates in that season by plants, the decay of vegetation, and the


UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER-SUPPLY PAPER
PACIFIC OCEAN
GULF OF MEXICO
NORTH DAKOTA
SOUTH DAKOTA
EXPLANATION
GROUND-WATER REGIONS
1. Western Mountain Ranges
2. Alluvial Basins
3. Columbia Plateaus
4. Colorado Plateaus and Wyoming Basin
5. High Plains
6. Unglaciated Central region
7. Glaciated Central region
8. Unglaciated Appalachian region
9. Glaciated Appalachian region
10. Atlantic and Gulf Coastal Plain
Ground-water areas after H. E. Thomas, 1951
Runoff contours after W. B. Langbein and others, 1949
Contours of annual runoff, in inches
Boundary of ground-water regions

GENERALIZED MAP SHOWING ANNUAL RUNOFF AND PRODUCTIVE AQUIFERS
IN THE CONTERMINOUS UNITED STATES

Figure 1-II-2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78,79

Notes: 1. Ref.: C.R. Taylor and E.R. Swanson, The Economic Impact of Selected Nitrogen Restorations on Agriculture and 20 Other Regions in the United States, University of Illinois at Urbana - Champaign, March, 1975.

2. List of areas corresponding to region number as available from the authors.

3. Crop production in the shaded areas is minimal.

Figure 1-II-3 Crop Producing Regions

decrease in tillage practices [1].

Figure 1-II-2 includes the surface runoff of water from the land. Relating this with the pattern of precipitation (Figure 1-II-5); an estimate of aquifer recharge potential is developed (Figure 1-II-4). It should be recognized that the soil retention level of the precipitation is not so high as would appear from Figure 1-II-5 [94]. Evapotranspiration accounts for much loss of water from the soil. In the arid regions west of the Mississippi River, there is often less than an inch of recharge whereas Figure 1-II-4 suggests several inches in most arid regions [54]. The Agricultural Research Service of USDA has investigated this rate for many soils and crops in connection with practices and climatic conditions. State and county extension services in many regions have developed data of this type also. The evapotranspiration rates are highly variable depending on a multitude of parameters [70].

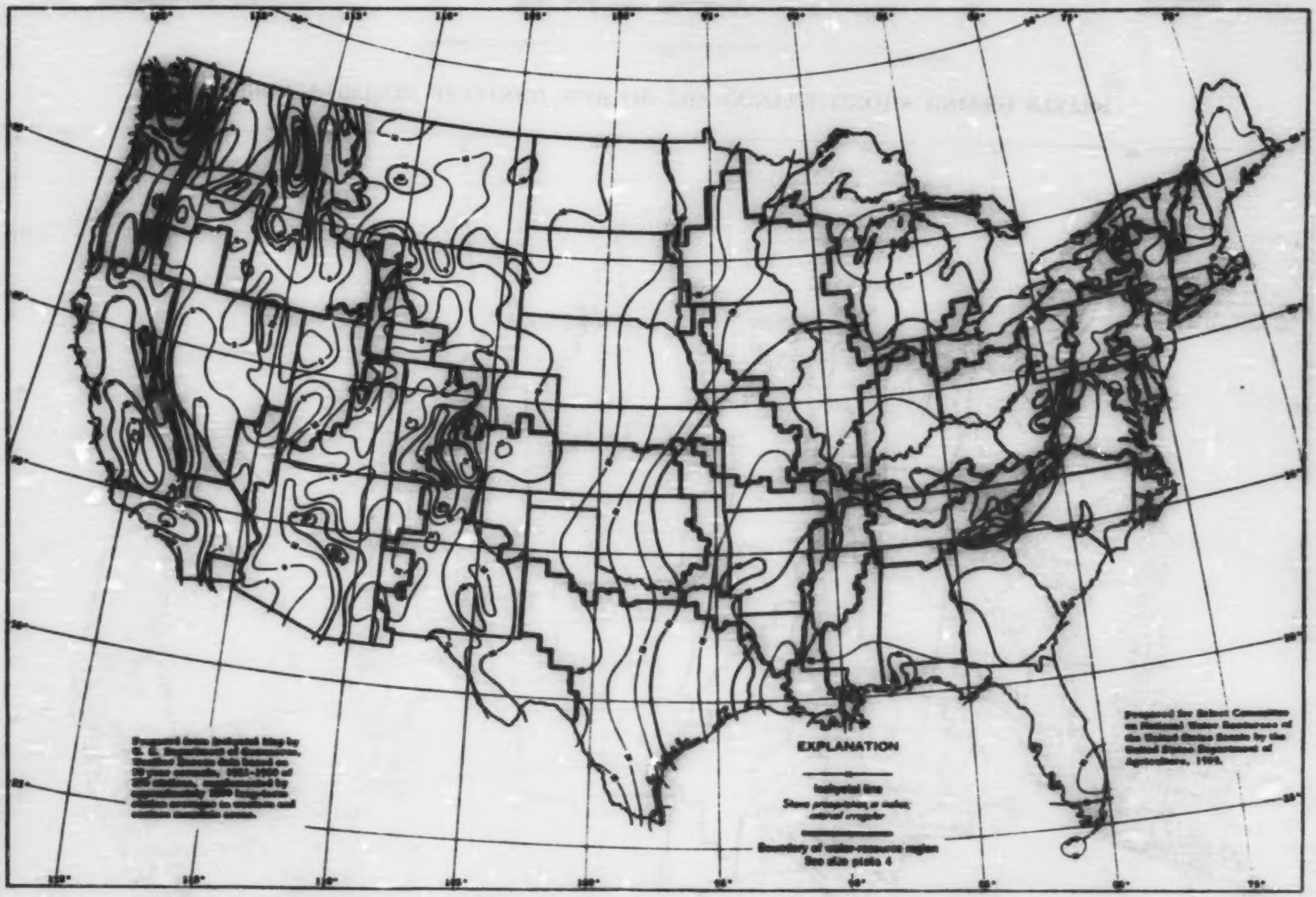
Data is presented in various forms and formats. The farm producing regions are presented by the U. S. Department of Agriculture as shown in Figure 1-II-6 [81]. The U. S. Bureau of Census lists fertilizer consumption with the regions divided as shown in Figure 1-II-7 [37].

There are several sources of data on fertilizer consumption. The U. S. Department of Agriculture publishes Agricultural Statistics and also Commercial Fertilizers, Consumption in the United States [78]. The U. S. Bureau of Census publishes Agricultural Statistics also [79]. The National Fertilizer Development Center of the Tennessee Valley Authority published the 1974 Fertilizer Summary Data (ed. Normal L. Hargett) [30], which gives an extensive breakdown of fertilizer usage by crop, state and composition. These data can be further defined by contacting individual state and local extension service units. The University of Maryland's Bureau of Business and Economic Research has projected consumption of fertilizers throughout the United States for the years 1971 through 1985. In 1974 there were approximately 175 million fertilized acres [37].

Feedlot statistics have been obtained through the U. S. Department of Agriculture, the EPA, and the Bureau of Census [77]. The University of Maryland's Bureau of Business and Economic Research has made predictions of growth rates of feedlot beef production through 1983 [37]. Further feedlot information is included in the "Feedlots" section of "Nitrates".

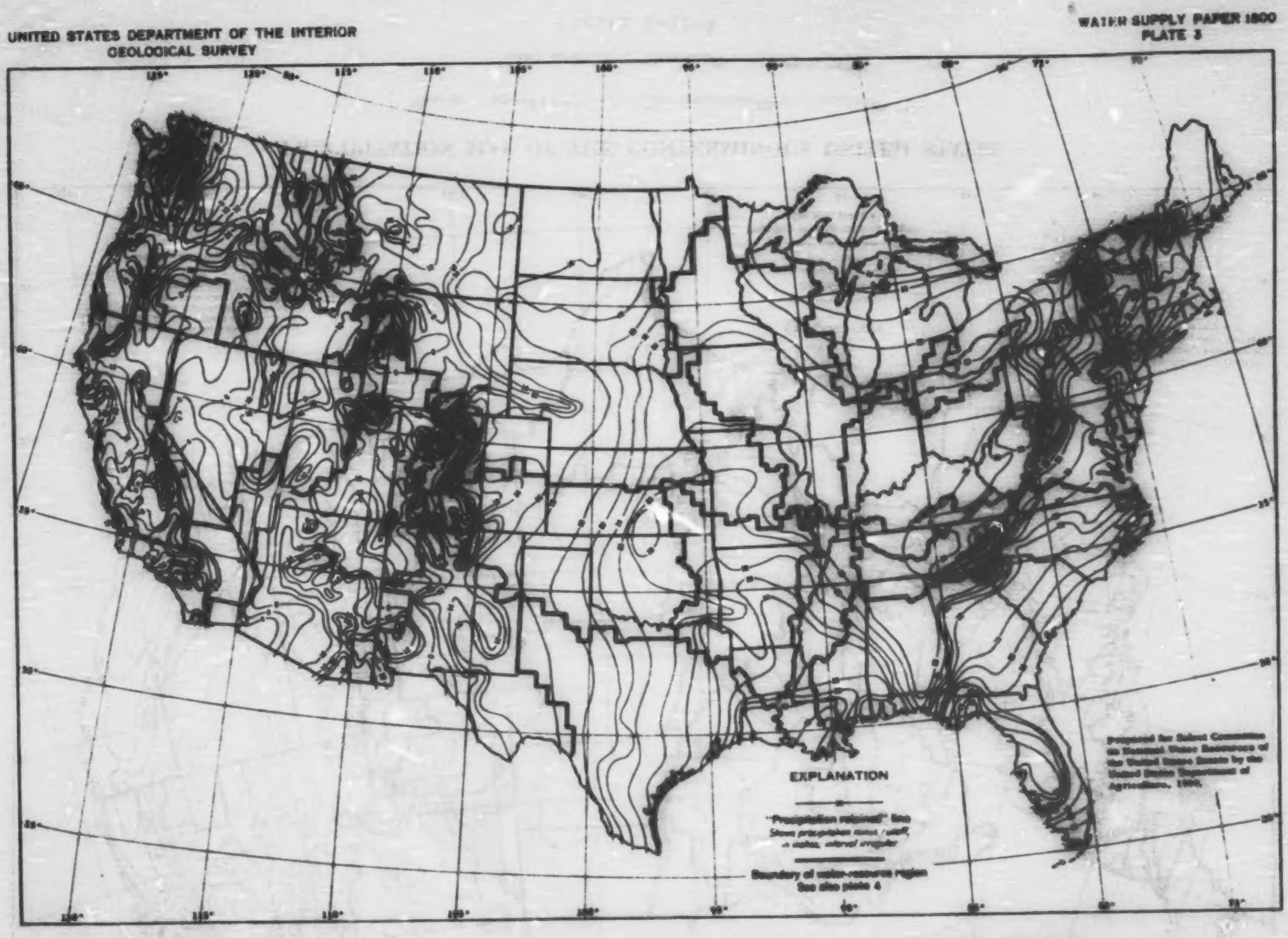
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-SUPPLY PAPER 1800
PLATE 2


Prepared from Isohyetal Map by U. S. Department of Commerce, Weather Bureau data based on 30 year normals, 1921-1950 of 270 stations, supplemented by approximately 1000 long-term station averages in western and eastern mountain areas.
EXPLANATION
Isohyetal line
Shows precipitation in inches; interval irregular
Boundary of water-resource region
See also plate 4
Prepared for Select Committee on National Water Resources of the United States Senate by the United States Department of Agriculture, 1960.
120°
115°
110°
105°
100°
95°
90°
85°
80°
75°
70°
25°
30°
35°
40°
45°
300 0 300 600 900 MILES
300 0 300 600 900 KILOMETERS

PRECIPITATION MAP OF THE CONTERMINOUS UNITED STATES

Figure 1-II-4


UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WATER SUPPLY PAPER 1800
PLATE 3
EXPLANATION
"Precipitation retained" line
Shows precipitation minus runoff, in inches. Interval irregular
Boundary of water-resource region
See also plate 4
Prepared for Select Committee on National Water Resources of the United States Senate by the United States Department of Agriculture.
125°
120°
115°
110°
105°
100°
95°
90°
85°
80°
75°
70°
45°
40°
35°
30°
25°

"PRECIPITATION RETAINED" MAP OF THE CONTERMINOUS UNITED STATES

300 0 300 600 900 MILES

300 0 300 600 900 KILOMETERS

Figure 1-II-5

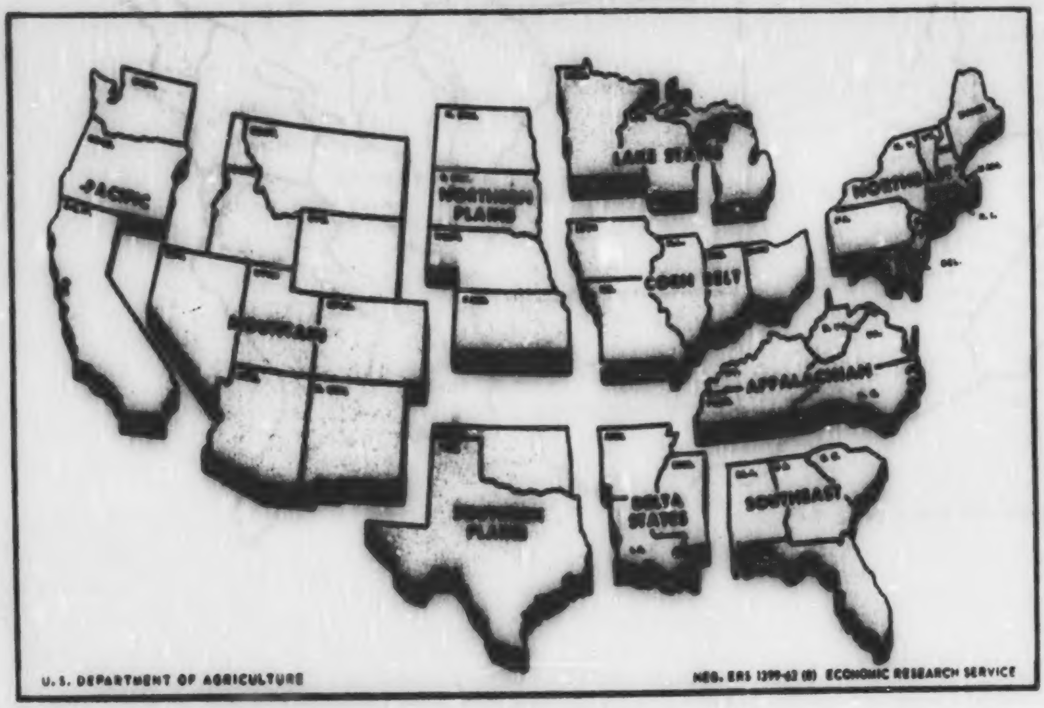
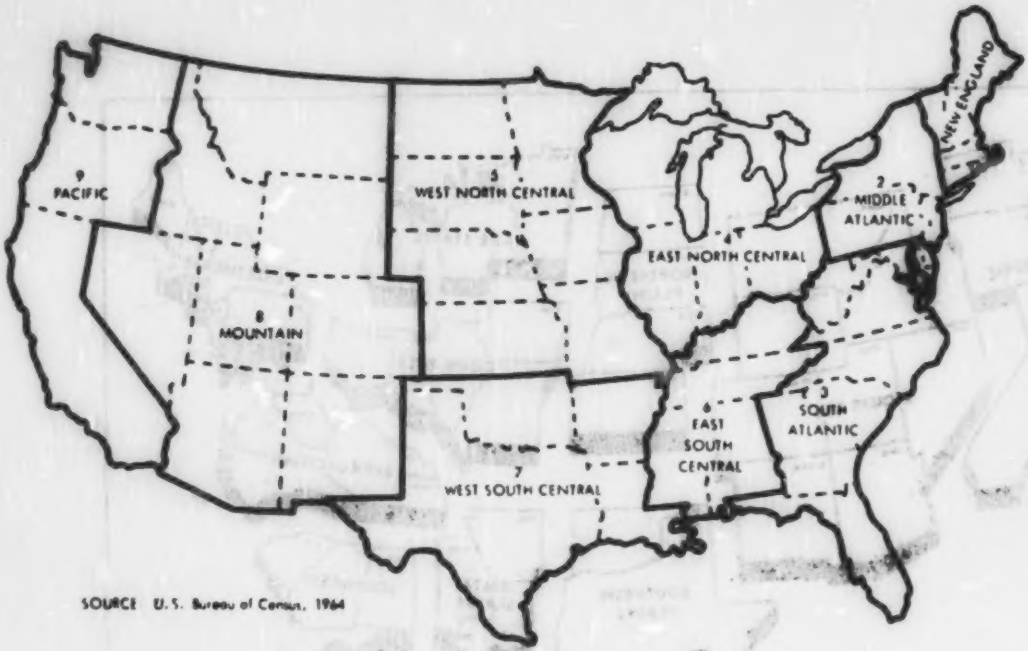

PACIFIC
MOUNTAIN
NORTHERN PLAINS
LAKE STATES
CORN BELT
NORTHEAST
APPALACHIAN
SOUTHERN PLAINS
DELTA STATES
SOUTHEAST
U. S. DEPARTMENT OF AGRICULTURE
NEG. ERS 1399-62 (8) ECONOMIC RESEARCH SERVICE

Figure 1-II-6

Farm Production Regions


9
PACIFIC
8
MOUNTAIN
5
WEST NORTH CENTRAL
4
EAST NORTH CENTRAL
2
MIDDLE
ATLANTIC
NEW ENGLAND
3
SOUTH
ATLANTIC
6
EAST
SOUTH
CENTRAL
7
WEST SOUTH CENTRAL

SOURCE U.S. Bureau of Census, 1964

Figure 1-II-7

Fertilizer-Consuming Regions in the United States

The distribution of soils [51] and geology throughout the United States has been compiled and mapped by the Soil Conservation Service (USGS sheet number 86, titled "Soils" [91] and USGS sheet number 74, titled "Geology") [92]. These mappings are not included in this report because of their size and detail and multicoloring. The soils map and the accompanying soils descriptions is very useful in conjunction with other maps to focus our attention on areas where problems of agricultural impact on groundwater are most likely to occur. The USDA has also an ongoing program for defining soil properties throughout the United States. State and local agricultural extension services have files on details of soils and some geology within their jurisdiction. Land grant colleges in each state have received Federal funds over the years and have studied local soils extensively. However, there is still a need to better characterise the relationships of soil, crop, and nitrate-N reactions in many areas.

The groundwater quality data, while still relatively limited, is available from several sources. It has come from the Soil Conservation Service, the U. S. Geological Survey, from state geological surveys (often the state programs are cooperative arrangements with the USGS), and EPA reports. Further soil, hydrology, and water quality information is available through the files of the Water Resources Departments and the Water Resources Research Centers of each state. The latter source is the more valuable source of information because of its research nature. The major problem involves access to the data. Although the data is available, it is not formally published, but exists in reports in files in the various centers and departments. Fortunately the centers do publish a list of the reports on a biweekly basis. A note of interest is that each Water Resources Research Center is given a grant of $100,000 a year by the Department of Interior [101]. It is anticipated that cooperation with these centers will be invaluable in identifying problems. Data on water table depths and aquifer profiles are compiled from well digger reports.

It should be noted that the mixing of agricultural pollutants in an aquifer is minimal because of the predominance of laminal flow in these bodies [95]. The nitrates and pesticides that do enter an aquifer through percolation tend to "float" in the upper level of the aquifer. When using well data to determine the degree of contamination in an aquifer it is important to know the depth in the aquifer at which the sample was taken. It is also important to know whether the draw down of the aquifer has been sufficient to bring waters from the upper layer into the pumped region.

The condition of the well casing can affect the water drawn. If the casing is permeable the well is very susceptible to seepage of nitrates and fertilizers into the aquifer.

Data taken during the Fall and Winter months will tend to show higher nitrate concentrations [2]. Data should therefore be identified as to the season in which it was taken.

Climatological data is obtained primarily from the National Weather Service of the National Oceanographic and Atmospheric Administration (NOAA). The data on surface runoff, evapotranspiration, and percolation through the ground are the realm of the USGS, Soil Conservation Service, the Corps of Engineers and to a lesser degree, the USDA.

## G. Groundwater Assessment

Generally, groundwater quality in the United States has not yet suffered severe degradation from agriculture. Locally, aquifers have been degraded due to operations of feedlots without proper controls or in connection with excessive and poorly timed fertilizer applications and other poor agricultural practices, including, in a few reported instances, careless pesticide applications. The objective is to prevent further deterioration of aquifers from which public drinking supplies are drawn. The second problem is to determine what future deterioration is to be anticipated with respect to various agricultural practices, with projected changes in operational parameters incorporated. This will require the use of mathematical modeling and computer simulation.

It is believed that as farmers become more scientific, and even more economical in their practices, the polluting impact of their operations will be reduced significantly. Two major points need to be considered: (a) more information is required on plant demand for nutrients and the proper rotation of crops to minimize nitrate percolation through soils [67]; (b) farmers must make better use of extension services and other good agricultural sources to determine the characteristics of their soils, even to the extent of fertilizing and planting their farms at different times and rates [102].

Feedlot waste handling and disposal needs further assessment [65]. New containment and application practices are now available and sometimes in use. A broad program of assessing the effectiveness of these techniques in preventing groundwater (and surface water, too) contamination is essential. This will require monitoring of various feedlot sites and the adjoining fields for a set of interesting locales (in terms of soil type, climate, animal population, etc.).

## III. NITRATES

### A. Nitrogen Cycle

High nitrate concentrations in drinking water are a potential health hazard and should be of concern to the user. They not only render the water unsafe for use in infant feeding, but generally indicate that the supply is contaminated [50].

The element nitrogen is a gas composing about 79 percent of the earth's atmosphere. It is relatively inert to chemical reaction and ordinarily does not occur abundantly in rocks or water, either in elemental form or in compounds. However, nitrogen and nitrogen compounds, which are essential to plant life and growth, do occur abundantly in soils and subsoils. Their presence there is due largely to bacterial action. Certain bacteria remove nitrogen from the air and fix it in plants and soils in the form of ammonia and more complex compounds, whereas other bacteria change nitrogen compounds from one form to another. Other sources of nitrogen compounds in the soil are nitrogen-fixing legumes, decomposing plant and animal tissues, animal and human wastes, nitrogen fertilizers, and surprisingly, lightning [19]. Because urea, a nitrogen compound in the waste of all animals, is readily converted to nitrate by bacterial action, barnyard and feedlot wastes are locally important contributors of nitrogen compounds to the soil. Septic tanks, cesspools, privies and sewage outlets to the soil, together with silo seepage, also are local sources of contamination. Ways in which nitrogen compounds accumulate in the soil and are changed from one to another are referred to as the nitrogen cycle.

There are three major forms of nitrogen in mineral soils: (a) organic nitrogen compounds associated with the soil humus, (b) ammonium nitrogen adsorbed by certain clay minerals, and (c) soluble inorganic ammonium and nitrogen compounds [50].

Most of the nitrogen in soils is associated with the organic matter. In this form it is protected from rapid microbial release, only 2-3 percent a year being mineralized under normal conditions [50]. About half the organic nitrogen is known to be in the form of amino compounds. The form of the remainder is uncertain.

Some of the clay minerals have the ability to fix ammonium nitrogen between their crystal units. The amount fixed varies depending on the nature and amount of clay present. Up to 8 percent of the total nitrogen in surface soils and 40 percent of that in subsoils has been found to be in the "clay-fixed" form [50]. In most cases, however, both these figures would be considerably lower. Even so, the nitrogen so fixed is only slowly available to plants and microorganisms.

In all soils there is considerable intake and release loss of nitrogen in the course of a year accompanied by many complex transformations. Some of these changes may be partially controlled by man while others are beyond his command. This interlocking succession of largely biochemical reactions constitutes the nitrogen cycle (See Figure 1-III-1) [4]. It has attracted scientific study for years, and its practical significance is beyond question.

The nitrogen income of arable soils is derived from such materials as commercial fertilizers, crop residues, green and farm manures, and ammonium and nitrate salts brought down by precipitation. In addition, there is the fixation of atmospheric nitrogen accomplished by certain microorganisms. The depletion is due to crop removal, drainage, erosion, and to loss in a gaseous form.

Much of the nitrogen added to the soil undergoes many complex transformations before it is removed. Proteins are converted into various decomposition products, and finally some of the nitrogen appears in the nitrate form. There are nitrification, mineralization, and denitrification processes which take place.

Mineralization (or ammonification) is the breakdown of organic nitrogen to ammonium. Nitrification is the oxidation of this ammonium, or ammonium from fertilizers, to nitrate. Factors affecting this process are soil characteristics, water content, aeration, and temperature. The rate of nitrification tends to decrease sharply when the oxygen content of soil falls below 2 percent or when soil air space is nearly saturated

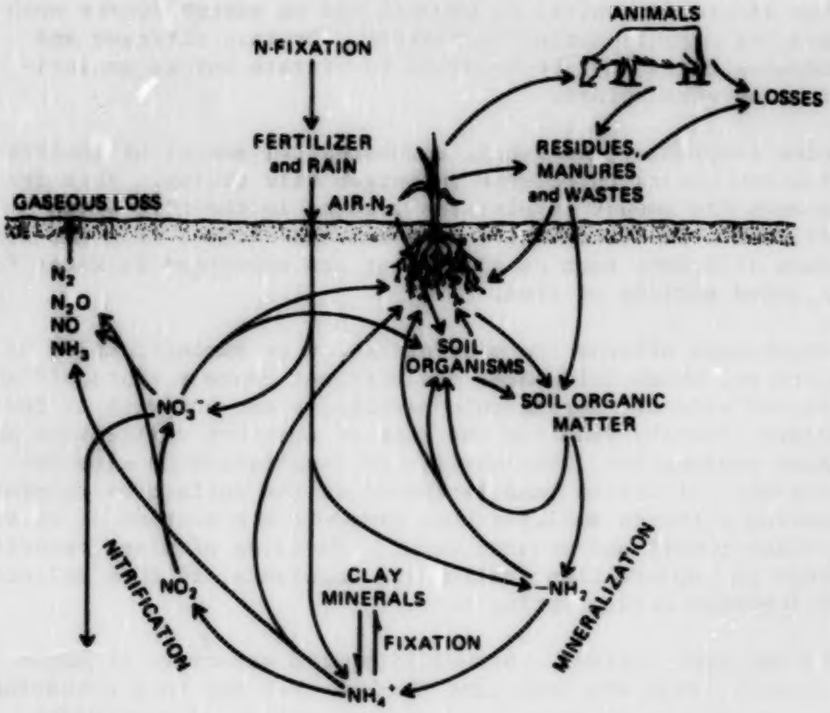

ANIMALS
N-FIXATION
LOSSES
FERTILIZER and RAIN
RESIDUES, MANURES and WASTES
GASEOUS LOSS
AIR-N$_2$
N$_2$
N$_2$O
NO
NH$_3$
SOIL ORGANISMS
SOIL ORGANIC MATTER
NO$_3^-$
NITRIFICATION
NO$_2$
CLAY MINERALS
FIXATION
-NH$_2$
MINERALIZATION
NH$_4^+$

Figure 1-III-1

Major Phases of the Nitrogen Cycle

with water. The maximum rate of nitrification occurs in soil temperatures of about 30° C. and is very slow at 7° C. Nitrate can be used by plants, denitrified, leached to groundwater, or remain in the soil and be available for subsequent crops.

Denitrification is the microbial reduction of nitrate to harmless nitrogen gas [4]. It is an important factor in determining the amount of nitrate available for leaching to groundwater. Denitrification generally takes place in soils when anaerobic conditions prevail and an energy source such as decaying organic matter is present. Organic nitrogen and ammonium forms must be oxidized to nitrate before denitrification takes place.

Under favorable conditions, a substantial amount of denitrification occurs in or near submerged tile drains. This decreases the amount of nitrates present in the tile drain effluent. Denitrification also removes nitrate from the root zones of crops, such as rice, that are submerged in water for extended periods of time.

Temperature affects the mineralization or ammonification of nitrogen, which influences the nutrient content of runoff and leached waters. During cold periods, plant activity is retarded, thereby reducing the rate of nutrient utilization and water consumption. Variability in temperature is also important. If frozen land is thawed at the surface by rainfall, leaving a frozen sublayer that prevents percolation of water, surface runoff and erosion occur. Freezing of plant material tends to rupture plant cells, and nutrients are then subject to leaching during spring thaw.

The nutrient content, permeability, and structure of agricultural soils are important factors that may have a bearing on the nitrate in ground and surface water. The nutrient accumulation in the soil and substrata is a function of basic soil properites, geologic deposits, decomposition of organic matter and peat, presence of nitrogen-fixing plants, soil organisms, animal and human wastes, and inorganic sources such as fertilizer and precipitation.

The energy associated with the impact of falling raindrops affects the amount of sediment in runoff and the rate of water infiltration. Adequate ground cover will absorb the raindrop impact and protect the surface cover. Forests and grasslands generally have higher rates of water infiltration than plantings of agricultural row crops when soil and slope conditions are otherwise equal.

Permeability and water retention characteristics of soil affect the amount of water passing through the root zone. If nitrate is present, it will move with the water and may eventually enter the groundwater. The concentration of nitrate in the groundwater depends on the amount of nitrate leached, the volume of water passing through the soil profile, and the transit time of the leachate from root zone to water table. Transit time is related to the hydraulic conductivity of the soil profile, depth of the water table, and degree of soil saturation. In some areas it may take 20-30 years for the leachate to pass from the root zone to the water table. A sandy soil will not retain as much water in the root zone as a loam soil, and so has a higher leaching hazard. Therefore, less nitrogen is utilized by plants and more nitrogen is leached below the root zone in sandy than in less permeable soils.

Geologic materials underlying soils may restrict the downward movement of water. Under such circumstances, nitrogen will not contaminate deep aquifers, but may accumulate in perched water tables.

Ordinarily, most of the nitrate in groundwater has been leached from the soil by infiltrating precipitation. Thus, where nitrate is especially abundant in the soil, the groundwater generally is high in nitrate. Very high concentrations in well water often are due to contaminants reaching the water table at or near the well site. For example, a poorly fitting well cover permits contaminants to enter the well directly, and open space or highly porous material surrounding the well casing permits contaminants to infiltrate rapidly to depths where they can enter the well through holes in the casing or through the screen. Shallow dug wells, particularly those walled with wood, stone, brick, or jointed tile, are the most likely to yield high-nitrate water owing to introduction of contaminants at or near the well site. Generally, high nitrate concentrations in water from deeper drilled wells are due to leaching of nearby tracts of nitrate-enriched soil and subsoil.

Drinking water standards have been set by the U. S. Public Health Service (1962) at a safety limit of 45 ppm nitration, or 10 ppm nitrate as nitrogen, as a safeguard for people using municipal water supplies. Although no limit has been set specifically for rural domestic supplies, the potential dangers of nitration concentrations greater than 45 ppm should be recognized.

## B. Health Effects of Nitrate

The best known problem due to nitrate consumption is methemoglobinemia, a cyanosis which is brought about by reduction of nitrate ($NO_3$) to nitrite ($NO_2$) by bacteria in the digestive tract, followed by absorption of the nitrite into the bloodstream where the nitrite oxidizes the ferrous ion ($Fe^{++}$) in hemoglobin to ferric ion ($Fe^{+++}$), thereby preventing the transport of oxygen by the hemoglobin. This results in a gradual suffocation (cyanosis). Infants are most susceptible since the acidity of their stomachs is considerably less than that of adults, resulting in a more favorable environment for the nitrate-reducing bacteria. The digestive system of animals such as cattle (ruminants) also is conducive to this bacterial action. Therefore, when a nitrate problem occurs, it is first reflected in health problems of cattle or human infants [50].

Methemoglobinemia is not well understood. The nitrate or nitrite concentration at which methemoglobinemia becomes a problem may vary widely, and is most likely influenced by some as yet unidentified factor or factors. Because of the methemoglobinemia problem, the U. S. Public Health Service has set a recommended maximum limit of 45 ppm nitration for potable water. However, water containing over 1000 ppm nitrate has been found with no apparent ill effects to the local population. In other areas, methemoglobinemia has resulted from using water with as little as 50 ppm nitration [9]. Clearly, more work is needed in the whole area of methemglobinemia.

One point deserves further clarification. The high susceptibility of animals. and human infants to methemoglobinemia derives from the bacteria in their digestive systems which can convert nitrate to nitrite. If the water which is being consumed already contains nitrite, however, even healthy adults will be susceptible. The presence of nitrite in drinking water results from at least two known causes. First, if the contamination is from surface pollution (e.g., barnyards or septic tanks) nitrite can be present due to incomplete oxidation of the nitrogenous waste materials. Second, nitrate in the groundwater can be reduced to nitrite by a chemical reaction with iron pipe or zinc coated (galvanized) pipe. This reaction consists of corrosion of the metal, with the nitrate acting as a hydrogen depolarizer.

Water contaminated with nitrate cannot be purified by boiling. The nitrate concentration will instead be increased due to the loss of water by evaporation.

There is increasing evidence that nitrate and especially nitrite may be linked to cancer. It was shown by Lijinsky and Epstein [43] that nitrite can react, under the conditions of temperature and acidity in the human stomach, with secondary amines (from cooked foods) to form nitrosamines, some types of which are highly carcinogenic. Other studies also indicate a relationship between nitrate and cancer. If such a relationship is proven, the Public Health Service limit of 45 ppm for nitration in drinking water will have to be reevaluated. In addition, it may be even more important to set limits on nitrite in drinking water.

Clearly not all the effects of nitrate are yet known; but it is believed that livestock may develop thyroid problems, rickets, enteritis, arthritis, and generally poor health from ingesting nitrates.

## C. Fertilizers

Fertilizer Nitrogen. Fertilizers are one of the major agricultural sources of potential pollution of the groundwater. The three major elements in fertilizers are nitrogen (N), phosphorous (P) and potassium (K). Nitrogen is the main pollutant in the form of nitrates. During 1973, 43 million tons of fertilizer material were applied throughout the United States, of which 8.3 million, 5.1 million, and 4.6 million tons were nitrogen, phosphorous, and potassium, respectively [30].

To meet the increasing demand for food by an expanding population, oxidized soluble forms of nitrogen have been introduced through new technology to supplement the slow process of nitrification and symbiotic N fixation. This effort has resulted in greater use of commercial nitrogen, often in addition to heavy application of manure. All nitrates are water soluble and have the potential to move into the groundwater and thereby create a potential health hazard. The atmosphere is usually considered to contribute from 2 to 6 pounds of nitrogen to an acre of land per year (Allison [3], Eliassen, et al [18], Hutchinson, et al [34]).

Several studies have been conducted on the occurrence of nitrite and nitrate in water supply systems (Smith [66], Doneen [15]; McHarg; Erwin, et al [20]; Murphy et al [49]). Very little is known of the extent of fluctuation in nitrate concentration in water wells. Contaminating sources have seldom been pinpointed. Environmental variables, well depth, well location, precipitation and agricultural practices contribute to the above fluctuations.

Nitrate derived from biological fixation of atmospheric nitrogen and nitrification are discussed in the following reports: Starky [71]; Hirsch [33]; Marshall, et al [46]; Brezonik [7]; McCoy [47]; Thompson [75], and other reports. Nitrate from naturally occurring deposits were discussed by Mansfield, et al [45], and Ingols, et al [35]. The intrusion of inorganic nitrogen originating from farmland as a potential source of nitrate-nitrogen in both surface and groundwater supply is discussed in the following papers: Corey, et al [11], Stewart, et al [72], Commoner [10], Krause, et al [40], Harmeson, et al [31], Welch and Kohl, et al [39].

The concentration of nitrate in groundwater is generally highest following wet periods and lowest during dry periods. Seasonal variations may be further enhanced by other factors such as geologic structures i.e.: characteristics and depth of soil, subsoil and bedrock formation, degree of and interconnecting crevices in rock formation, presence of a rechargeable aquifer and amount of recharge water, as well as amounts of nitrogen applied.

Olson reported that the maximum downward migration rate of $NO_3$ in silt loam soil is in the range of 1 to 1-1/2 feet per year. The rates for sandy soil will be much higher while those for clay soils will be lower.

Shallow wells (less than 50 feet in depth) are more apt to show large and frequent increases or decreases of nitrate concentration. Deeper wells tend to show less intensity of nitrate fluctuations.

Efforts to obtain higher yields per unit of land through fertilization, whether the fertilizer is organic or inorganic, nearly always create greater potential for nitrate to be carried into waterways. When the efficiency of nitrogen use becomes low, greater losses of nitrogen occur, particularly in well drained soils, and the nitrogen may then escape to leaching waters. Low cost fertilizers tend to encourage inefficient and excessive usage of nitrogen fertilizer on the farm.

Because intensification of agriculture favors greater decomposition of native soil nitrogen, the nitrate content of underground waters may rise. However, in oxygen-deficient soils with high water tables, the nitrate may be converted to nitrogen gas.

In humid regions, the nitrate concentration in water percolating through cultivated soils is a function of the fertility level of the soils. The amounts of water percolating through the soil at any given time, the degree of nitrate removal by crops, and the activity of denitrifying microorganisms determine the nitrate concentration in soil leachates.

Industrial nitrogen fertilizers may cause some temporary changes in the biological processes essential for soil fertility, but the changes are neither permanent nor irreversible. The benefits of fertilizer use, associated with the increased availability of an element essential for plant growth, far outweigh the temporary inhibition of certain soil microorganisms.

Reducing nutrient losses to groundwater from agricultural nonpoint sources can be accomplished with two general approaches: (a) determining and applying appropriate amounts of plant nutrients at the proper time and in the proper place, and (b) adopting improved cultural practices, including conservation tillage and crop rotations, that minimize nutrient losses. Control measures should be selected in light of their economic and technical feasibility, as well as their effect in reducing nutrient losses.

Phosphorous in Fertilizers. When fertilizer phosphate is added to the soil it is rapidly incorporated into relatively insoluble compounds. Because of the insolubility of these compounds, leaching losses are minimal and so groundwater contamination from fertilizer phosphorous is not a problem. Phosphate compounds are generally non-toxic, but tend to cause eutrophication of surface waters.

Potassium in Fertilizers. The third macronutrient commonly added to soils is potassium. Little is known about its function in plants. Drainage waters from soils to which potassium has been added have been shown to contain considerable quantities of potassium. In other instances, more than 90 percent of the added potassium has been recovered by crop removal.

Leaching of potassium depends on the mineral composition, the amount of soluble organic matter, and the base exchange capacity of the soil.

Potassium has not been found to be harmful to humans or livestock. On the contrary, potassium is known to be essential to muscle tissues in animals. Some people have been found to have a potassium deficiency. Though potassium may enter a groundwater supply, its effects have not been found to be harmful.

## D. Feedlots

Animal Wastes/General. Livestock and poultry production in the U. S. is becoming concentrated in large scale, confinement type operations. These include multi-hundred - cow dairy operations, multi-thousand - head beef and hog feedlots and enterprises with many thousands of birds. Such large concentration of animals and birds have greatly magnified the problem of handling the animal wastes. Production of wastes by livestock is summarized in Table 1-III-1 [98]. Population equivalent by various kinds of livestock is given in Table 1-III-2 [98]. For example, a feedlot of 10,000 head of cattle has about the same waste disposal problem as a city of 164,000 people. Such a city will use approximately 8.2 mgd to carry off the sewage [98]. Such quantities of water are never used and seldom available at feedlots. The composition of some animal wastes are given in Table 1-III-3 [57].

The primary problem in handling animal wastes involves coping with the high BOD. Untreated municipal sewage has a BOD of about 100 to 400 ppm. Wastes carried in runoff from barnyards and feedlots may vary in BOD from 100 to 10,000. Many installations use lagoons for oxidation but success has not been complete. Such wastes, when deposited on the soil, can lead to higher nitrate concentration as well as higher salt loads in the adjacent waters, surface and underground.

Heterotrophic Nitrification. The nitrate in soil and groundwater may originate from microbial transformation of manure returned into the soil. Traditionally, nitrification was considered the work of autotrophus in which ammonium is oxidized to nitrite and subsequently, to nitrate. Heterotrophic nitrifiers have been reported as potential nitrate by Hirsch, et al [33], and Marshall, et al [45]. Thus, the compounds important for nitrification are no longer limited to inorganic nitrogen but include a series of amino acids (peptides) which may be converted to nitrates. Thompson (1969) concluded that it is reasonable to assume that nitrate pollution of groundwater may be attributed to heterotrophic nitrifiers where large amounts of wastes are returned to the soil.

Denitrifying Organisms. Present day farming practices often lead to situations in which nitrates accumulate faster, by nitrification due to heavy application of commercial fertilizers, than they are removed by either crops or denitrification. Crabtree (1972) reported that the total number of

## TABLE 1-III-1

Production of wastes by livestock in the United States. [98]

| Livestock | U.S. population 1965 | Solid wastes[1] | Total production of solid waste | Liquid wastes | Total production of liquid wastes |
|---|---|---|---|---|---|
| | Millions | G./cap./day | Million tons/yr. | G./cap./day | Million tons/yr. |
| Cattle | 107 | 23,600 | 1,004.0 | 9,000 | 390.0 |
| Horses[1] | 3 | 16,100 | 17.5 | 3,600 | 4.4 |
| Hogs | 53 | 2,700 | 57.3 | 1,600 | 33.9 |
| Sheep | 26 | 1,130 | 11.8 | 680 | 7.1 |
| Chickens | 375 | 182 | 27.4 | --- | --- |
| Turkeys | 104 | 448 | 19.0 | --- | --- |
| Ducks | 11 | 336 | 1.6 | --- | --- |
| Total | --- | ------ | 1,138.6 | ----- | 435.4 |

[1] Geldreich and others.

[2] Horses and mules on farms as work stock.

### TABLE 1-III-2

Population equivalent of the fecal production by animals, in terms of biochemical oxygen demand (BOD). [98]

| Biotype | Fecal (G./cap./day) | Relative BOD/ unit of waste (lb.) | Population equivalent |
|---|---|---|---|
| Man | 150 | 1.0 | 1.0 |
| Horse | 16,100 | 0.105 | 11.3 |
| Cow | 23,600 | 0.105 | 16.4 |
| Sheep | 1,130 | 0.325 | 2.45 |
| Hog | 2,700 | 0.105 | 1.90 |
| Hen | 182 | 0.115 | .14 |

## TABLE 1-III-3

## Average Daily Manure Production and Composition [57]

| ITEM | HOGS (lb/d) | CHICKENS (lb/d) | CATTLE (lb/d) |
|---|---|---|---|
| Wet Manure | 7.000 | 0.2500 | 64.00 |
| Total Solids | 1.120 | 0.0720 | 10.20 |
| Volatile Solids | 0.950 | 0.0550 | 8.20 |
| Nitrogen | 0.050 | 0.0040 | 0.38 |
| $P_2O_5$ | 0.030 | 0.0031 | 0.11 |
| $K_2O$ | 0.048 | 0.0014 | 0.31 |

(After Proctor, 1964)

denitrifiers increased as the rate of manure application increased. Denitrifying bacteria were found regardless of aerated or water logged soils, with or without the presence of detectable nitrites or nitrates. Denitrification and nitrate reduction by heterotrophics may occur only when a sufficient amount of nitrite or nitrate is present in a given microbial environment lacking in other more suitable hydrogen acceptor.

A question inevitably raised is why the accumulation of such high nitrate content in the groundwater supply exists in the presence of large number of nitrifiers. A reasonable explanation is that the denitrifying bacteria formed may not be active in the denitrification process because the soils are sufficiently aerobic or lacking in hydrogen donor compounds; aerobic conditions inhibit the denitrification process regardless of the presence of nitrates.

Feedlot Operations. Presently, the large, mechanized commercial feedlot accounts for many of the livestock fed for slaughter. In the past, animals were fed in small units, and wastes were considered an asset. Today, the concentration of many animals in one unit creates enormous waste-management problems. A cattle feedlot of 50,000 capacity covers approximately 200 acres and produces approximately 450,000 tons of wet manure and urine annually. This manure contains about 15,000 tons of dry mineral matter, 60,000 tons of dry organic matter, and 2,800 tons of nitrogen. Pollution of groundwater can occur directly beneath the pens, beneath basins used to impound runoff, and beneath cropland treated with wastes or runoff from the feedlots.

Increased nitrate concentrations found in Missouri water supplies have been attributed to feedlots and not to fertilizer use on farms. In a Colorado study [72] profile, samples were obtained from the surface to bedrock or to the water table. Nitrate content of the profiles was influenced by land use. Nitrate content in 20 feet of profile under cattle feedlots was as high as 5,000 lb per acre, the average for 47 feedlots being 1,436 lb. For other kinds of land use the average values were: virgin grassland, 90 lb.; unfertilized wheat-fallow land, 261 lb.; and irrigated land not in alfalfa, 506 lb. Nitrate gradients in the profile showed accumulations at the soil surface, with concentrations decreasing with depth. Nitrate content in the water at the water table surface, and at the 20 ft. depth in the soil showed little difference for each land-use [72]. The question is what happened to the nitrate? There was evidence that water was moving through the profile and that some nitrate was moving with it. The decrease in nitrate with depth was attributed to denitrification, the process whereby microorganisms reduce nitrate to nitrogen gas. The greatest decrease in nitrate concentration occurred under feedlots where an abundant supply of carbonaceous material was present in the soil water to serve as an energy source for the microorganisms. Denitrification, therefore, appears to be significant in determining the fate of nitrate moving through soil profiles, particularly those under barnyards and feedlots.

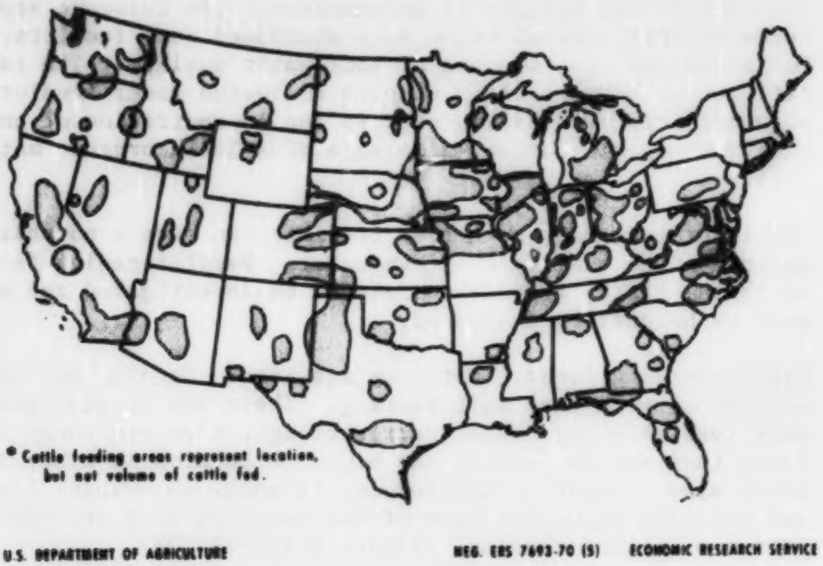
Even if nitrate concentrations remain low, other pollutants can degrade the quality of groundwater. The Colorado study revealed that several wells were abandoned near feedlots, even for livestock use, because of poor water quality. The largest differences between water samples collected under feedlots and adjacent irrigated fields were in the concentration of ammonium and organic carbon, a measure of soluble organic matter [72].

The literature has shown that feedlots can have a notable impact on the quality of groundwater. Feedlot design factors which may affect groundwater should be investigated and management techniques re-evaluated.

Cattle-Feeding Areas. Not long ago cattle feeding was almost synonymous with Corn Belt feeding. There the surplus grains were available for feeder cattle brought from the range areas. Since then cattle feeding has begun to develop in other regions also. Areas in California, Arizona, the Plains States, and Colorado represent some of the newer centers of concentration of cattle feeding. (Figure 1-III-2) [77].

Cattle feeding is a major activity in those areas where the combination of feed supplies, feeder cattle, markets, and other resources are favorably balanced. In each region, however, there are specific locations in which feeding operations are concentrated. Some of these locations cover broad geographic areas, as in the northern portion of the Corn Belt while in other regions, the industry is confined to small areas. The fed cattle marketed in 23 major states is given in Figure 1-III-3 [65].

Nearly all parts of the country now have some cattle feeding. Such regions as the Southeastern and mountain States account for hardly more than 2 or 3 percent of the number of cattle fed nationally, but each region has several areas of concentration. These areas are small, but their level of output



* Cattle feeding areas represent location, but not volume of cattle fed.

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Figure 1-III-2

Cattle Feeding Area

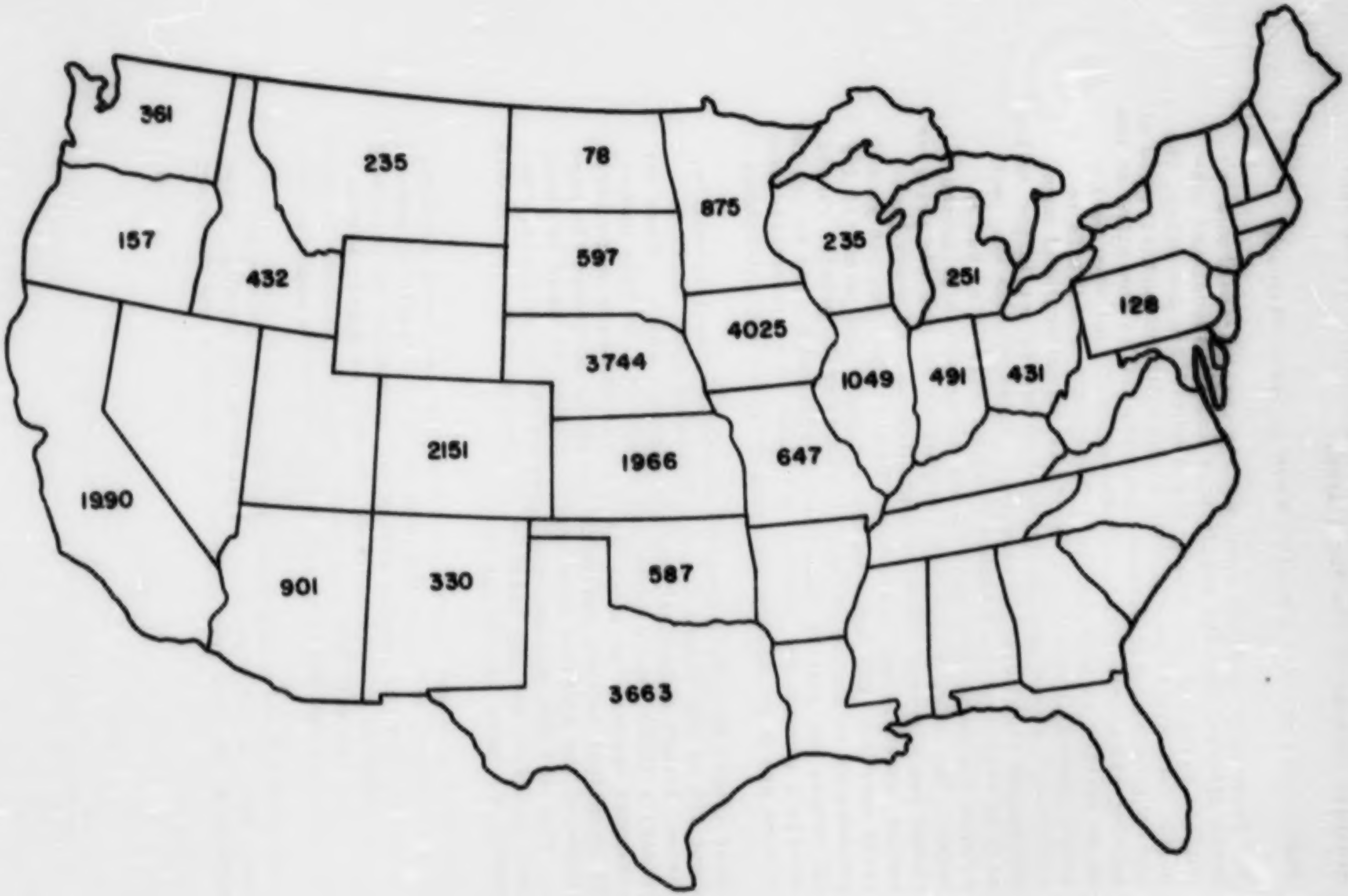
361
157
1990
432
235
901
2151
330
78
597
3744
1966
587
3663
875
4025
647
235
1049
251
491
431
128

Figure 1-III-3

Feed Cattle Marketed in 23 Major States

is sufficient to make feeding of significance to the agricultural economy of the local areas.

## E. Septic Tank Systems (On Site Domestic Waste Disposal)

The three most commonly used systems for on site domestic waste disposal are the septic tank and its associated subsurface distribution system, the cesspool and the privy. The septic tank system is the most acceptable and sophisticated of the on site domestic disposal methods, and is installed at new housing sites when local ordinances permit and when public sewer service is unavailable. The cesspool, which is no longer generally approved, is usually an underground sump filled with stones and is intended to settle out larger solids discharged from domestic plumbing. These systems work well only in very coarse or highly fissured materials, but in essence discharge raw sewage which moves easily to groundwater. The privy is usually designed as an open pit privy or closed vault privy. These are usually located where pressurized water is not available. Because the open pit generally receives only human wastes and paper the potential for groundwater pollution is small. Closed vault privies retain all wastes and must be pumped out periodically, and so are not usually a groundwater problem. Problems often associated with privies are odor, disease-carrying insects, and maintenance.

About twenty million individual housing units, representing about 29% of the United States, discharge their domestic wastes through individual on-site disposal units. These are primarily (85%) septic tanks and cesspools. Of this number cesspools account for about two hundred thousand units [89]. The principal factors and variables which determine the magnitude of the problems from septic systems as would be found on farms are the geology, the depth to the water table, the precipitation, and the location and design of the system with respect to other facilities [42].

Individual problems of well contamination can occur anywhere in the country, but when the problem is the result of contamination from the septic system it can usually be corrected by the redesign or relocation of the well or septic system. Very often the well has been poorly cased or located, in which event nitrate and coliform contamination can be expected [89].

Areas in which there are less than 10 septic systems per square mile do not present a threat to public drinking water supplies which draw from groundwater, except where the septic system is located too close to the well and causes direct contamination [89].

It is hard to differentiate the effects of nitrate pollution of groundwater by a septic system from those of a barnyard or feedlot, if these sources are within close proximity of each other.

Data on the density of septic systems has been obtained through the 1970 Census of Housing [83]. The control of septic systems is generally through local, county, or state agencies. The records of well contaminations and septic tank failures are kept in the files of these agencies. The individual Water Resources Research Centers also have collected data within their jurisdictions. Most state Environmental Health Departments will test water samples for nitrates free of charge.

Within the EPA the Office of Air and Waste Management has a Solid Waste Management Program that includes the assessment of problems created by septic tank systems. They are presently engaged in determining the dimensions of this problem [89]. EPA's R. S. Kerr Environmental Research Laboratory at Ada, Oklahoma, has recently initiated a long term septic system study.

## IV. AGRICULTURAL PESTICIDES

### A. Introduction and Overview

In 1964, 693 million pounds of agricultural pesticides - insecticides, fungicides and herbicides - were applied to some 83 million acres of land [98]. When these chemicals are applied directly to the environment, it is obviously impossible to avoid exposing most, if not all, of the organisms in our environment to the insecticides. In addition, these chemicals may not only be hazardous to non-target living organisms but may move to other parts of the environment by various vectors [24].

The potential hazard of an agricultural pesticide as a groundwater contaminant depends on its solubility, adsorption characteristics, and biodegradability [87]. A pesticide may be extremely toxic, but if its chemical composition is unstable, is rapidly biodegradable or has a low solubility, it may not pose a hazard because it may never reach the groundwater.

In general, pesticides used in agriculture can be grouped into five major classes. Each of these classes has certain physical and chemical characteristics which are of primary importance in evaluating the potential hazard of such a class as a groundwater pollutant. These five classes of pesticides are: organic botanicals, organic phosphates, carbamates, chlorinated hydrocarbons (CH) and organometallic compounds. A brief discussion on the potential of each one of these classes for contaminated groundwater supply is given below.

Chlorinated hydrocarbons are among the most stable of all pesticides in use today [28]. Some of the most noted pesticides of this group are DDT, aldrin, dieldrin, endrin, lindane, chlordane, heptachlor and toxaphene.

These pesticides produce long-lasting toxic residues that are stable in a wide variety of environmental conditions. In some cases the residues or metabolites may be more toxic than the original pesticides. Chlorinated hydrocarbons are known to have extreme longevity [67].

Nash and Wilson (1971) reported that 39 percent of the original DDT applied to a test plot was recoverable after 17 years. Dieldrin was reported to be even more stable than DDT. Terriere (1956) investigated the persistence of various chlorinated hydrocarbons and concluded that dieldrin is the most persistent. The retention and releases of chlorinated hydrocarbon residues from soils is dependent on many factors. Temperature, soil type, and solubility of the pesticide are the most important factors. Studies in Wisconsin by Lichtenstein (1962) suggest that persistence is also influenced by the chemical specificity of the insecticide, soil, moisture, cover crop, soil cultivation, mode of application and soil micro-organisms [97].

Lichtenstein (1956, a) reported no residue release from chlorinated hydrocarbons where soils are frozen; under higher temperatures there is a positive correlation between temperature and the amount of residue released from CH (chlorinated hydrocarbons). Swanson (1954) concluded that adsorption and not cation or base exchange was the principal mechanism in retaining lindane residues in soils. High organic content soils were shown to retain more CH residue than sandy or mineral soils. Similar results were obtained by Lichtenstein (1959, b). Wheatley (1960) determined that the half life of dieldrin in a mineral soil is approximately four years while the half life in an organic soil is approximately five to seven years. Thus, it can be concluded that the organic content of the soil is a dominant factor in the retention of CH pesticides residues.

CH pesticide residue can be removed from soil by plants as was demonstrated by Wheeler (1967). A few microorganisms are capable of degrading dieldrin but the factors involved in microbiological degradation are complex and not well understood (Matsumura 1960).

Due to adsorption processes in soil, the chlorinated hydrocarbons and their metabolites do not normally percolate into the subsoil [68]. However, in soils, such as montmorillonite, which are high in clays of an expanding nature, pesticides can be transported readily through the cracks which form in these soils during dry weather. Chlorinated hydrocarbons have been found as deep as 70 feet under these conditions [102].

Even though several of the chlorinated hydrocarbon pesticides have had their registrations cancelled in the U. S., their residues may still be present because of their chemical stability and therefore they may be a potential hazard to groundwater. The registration of DDT, aldrin, dieldrin, and endrin have been cancelled. Chlordane and heptachlor are presently being considered for cancellation.

Contamination of groundwater by CH pesticide residue is dependent on their solubility in water as well as adsorption in the soil matrix. CH pesticides are considered to be only slightly soluble in water. Tests by the Georgia Agricultural Experiment Station [98] have shown that: (a) lindane was one of the most readily leached; 54 to 88 percent of this chemical was removed from six soils, (b) no trace of endrin was found in the leachate from three soils but 51 to 95 percent of that added to the other three soils was leached, (c) dieldrin showed wide variability in behavior among six soils. Only 1 percent was leached from Magnolia sandy loam, whereas 65 percent was removed from Lakeland sand. Results from the other four soils were scattered in between these extremes, (d) Aldrin was very resistant to leaching. Only a trace was removed from five of the soils and 16 percent from the Lakeland sand, (e) Heptachlor also was very resistant to leaching. It is interesting to note that these results were obtained from six sandy soils found within a 50 mile radius of Tifton, Georgia. One can only conclude that a greater scatter in the results will occur if a wider range of soils obtained from different parts of the United States is used.

Eye [21] concluded that for one foot of penetration of dieldrin residue level of 20 ppb, water must infiltrate a distance of 360 to 480 feet into the soil. However, the number of cases where groundwaters were reported CH contaminated in the literature is minimal.

It is difficult to estimate the degree of contamination of groundwater resources because well-water analyses of CH are not common. In addition, data on CH residue in groundwater is usually not reported in the literature unless it is a part of some particular study.

In view of the evidence reported in the literature surveyed it is likely that chlorinated hydrocarbon-pesticide residue can be a slight hazard to deep groundwater aquifers. However, in areas where shallow water table aquifers are present, a real potential hazard exists.

Carbaryl type pesticides containing nitrogen, such as Sevin, break down in the soil in a comparatively short time and the resultant metabolic products are non-toxic. No health hazards are known to exist from carbaryl pesticides at the present time [17].

Triazine type heterocyclic pesticides such as diazinone and triazinone and their metabolites persist much longer in the soil [99]. Very little is known about the metabolites of diazinones or triazinones with regard to toxicity or solubility. Chemical literature is still lacking on groundwater pollution by these pesticides. They have not yet been found to be groundwater pollutants.

Organophosphorous and organosulfur pesticides are broken down easily and rapidly in soil and subsoil. These compounds are commonly called nonpersistent pesticides because they are degraded to less toxic compounds in a relatively short time (3-6 months, according to some studies) [102]. The degradation of these compounds is achieved by sunlight, soil bacteria, and water. Because of the instability of the original chemical structure and of the less toxic, biodegradable secondary compounds, it isunlikely that such compounds may contaminate deep groundwater sources. The time required for these compounds to reach deep groundwaters is sufficient for soil bacteria to attach and degrade them.

Organometallic pesticides are those which contain metallic elements in the structure. There are spotty references to those toxic metals. More emphasis is put on arsenic-containing pesticides [41]. Arsenic reacts with the cations of iron, aluminum and calcium. These are water insoluble metallic arsenates which pose no health hazard to groundwater. The presence of phosphorous in the soil affects the phytotoxicity of arsenic. Phosphorous and arsenic are in the same periodic group and hence have similar chemistry. Arsenic is removed from the soil by bacterial metabolism which transforms it into arsenic hydride and its methyl derivatives. These metabolites are gaseous and easily removed by volatilization. Many of the metallic elements in this group of pesticides have been found to persist in the soil and interfere with plant growth, but apparently pose little hazard to groundwater.

Organic botanicals are pesticides derived from plant matter [28]. Such pesticides are manufactured either by extracting naturally occurring insecticidal compounds from plants or by grinding plant matter - roots, stems, leaves - of plants which contain certain insecticidal compounds. Because of their origin organic botanicals are quite low in toxicity, both to plants and warm-blooded animals. Their primary use is in home gardens and control of household insects. Although these compounds are widely used in households, they are of limited use in agriculture because of their high cost, very specific action and a tendency to deteriorate in storage. In general organic botanicals have low solubility in water and are rapidly biodegradable, a characteristic which will tend to limit their potential as a source of contamination of groundwater. Some of the common members of this group are nicotine sulfate, rotenone and pyrethrins.

Only a limited number of instances of groundwater contamination by pesticides and herbicides have been reported in the literature. It is unlikely that groundwater contamination from these sources is a serious problem nationwide; as was pointed out earlier, only chlorinated hydrocarbons residues are persistent and therefore of concern [102]. A study conducted by Eye [21] concluded that for one foot of penetration of dieldrin residue at a residual level of 20 parts per billion, water must infiltrate from 360 to 480 feet into the soil. Crosby [13] suggested that if an effective rainfall of about ten inches infiltrated a given area it would remove only 0.003 of a gram of dieldrin residue per square foot and transport it to a depth of approximately one-half inch. The soil for this case was sandy silt with about 20 percent clay. Because of the low solubility, partial degradation, uptake by plants, biological attack, volatilization and co-distillation, contamination of groundwater sources by CH residue on a national scale is not believed to be a problem. However, in certain areas, local contamination of groundwater may occur; this would be primarily in areas of soils of very high permeability, high water table, and/or slow moving groundwater.

Data on intensive farming regions where CH pesticides have been used heavily are available from standard sources (e.g., U. S. Census Bureau) and also through the U. S. Department of Agriculture, Federal and state agricultural experimental stations, agricultural extension services, and the EPA. The data on soils and hydrology can be obtained from the Soil Conservation Service, U. S. Geological Survey, USDA, state geological surveys, the Water Resource Department of each state, and the Water Resources Research Center of each state. The USDA's Agricultural Statistics is a particularly useful data source.

## B. Preliminary Correlation Between Organics Found in Drinking Water and Specific Pesticide and Fertilizer Uses

The nationwide occurrence of organic compounds identified in drinking water are listed in Table 1-IV-1 which follows [96]. Those which are active ingredients in pesticide formulations are listed in Table 1-IV-2 and those which are inactive ingredients, such as solvents, are listed in Table 1-IV-3.

The list of compounds in Table 1-IV-1 comprise the total organics identified in drinking water but are only a small fraction by weight of the total organics in drinking water [96].

Many of the chemicals which appear on Table 1-IV-1 could be chemical or biochemical degradation products of pesticide formulations, both active and nonactive ingredients. There is no evidence of fertilizer ingredients.

The majority of pesticides in drinking water arises from agricultural and urban runoff. A significant number of the chemicals listed on Tables 1-IV-2 and 1-IV-3 are chlorinated which is the more persistent category. To help put this matter of organic pesticide correlation with organics in perspective it has been determined that for one foot of penetration of dieldrin residue at a residual level of 20 ppb, water must infiltrate from 360 to 480 feet into the soil [103]. This throws some light on the likelihood the correlation which exists for surface water pesticides and organics occurring for ground water.

## TABLE 1-IV-1

## Organic Compounds Identified in Drinking Water*

acenaphthylene
acetic acid
acetophenone
aldrin
de ethyl atrazine
behenic acid, methyl ester
benzene sulfonic acid
benzopyrene
benzothiophene
borneol
bromochlorobenzene
bromoform
bromophenyl phenyl ether
butyl bromide
e-caprolactam
carbon tetrachloride
chlorobenzene
b-chloroethyl methyl ether
chlorohydroxy benzophenone
chloromethyl ether
m-chloronitrobenzene
o-cresol
DDT
dibromobenzene
dibromodichloroethane
1,4-dichlorobenzene
1,2-dichloroethane
dieldrin
di(2-ethyl hexyl) phthalate
dihydrocarvone
di-isobutyl phthalate
1,3-dimethyl naphthalene
2,4-dimethyl phenol
acanaphthene
bladex
chlordene
crotonaldehyde
cycloheptanone

acetaldehyde
acetone
acetylene dichloride
atrazine
barbital
benzene
benzoic acid
benzothiazole
benzy butyl phthalate
bromobenzene
bronodichloromethane
bromoform butanal
butyl benzene
camphor
carbon disulfide
chlordane
1,2-bis-chloroethoxyethane
chloroform
b-chlorethyl methyl ether
chloromethyl ethyl ether
3-chloropyridine
DDE
decane
dibromochloromethane
dibutyl phthalate
dichlorodifluoroethane
dichloroethyl ether
diethyl phthalate
dihexyl phthalate
di-isobutyl carbinol
1,2-dimethoxybenzene
dimethyl sulfoxide
dimethyl phthalate
benzaldehyde
carbon dioxide
1-chloropropene
cyanogen chloride
1,3-dichlorobenzene

*Source: "Identification of Organic Compounds in Effluents from Industrial Sources"
Prepared for Office of Toxic Substances - EPA
Prepared by Versar Inc., Springfield, Virginia
April, 1975, EPA 560/3-75-002

1,1-dichloro-2-hexanone
dichloropropane
di-(2-ethyl hexyl) adipate
diphenyl hydrazine
p-ethyl toluene
hexachlorophene
methyl methacrylate
pentachlorophenyl methyl ether
propazine
trimethyl benzene
o-xylene
m-xylene
alachlor
butyl octyl maleate
ethyl acetate
1,1,1-trichloropropane
methyl-2,3-dihydroindene
tetrachlorophenol
methyl cyclohexane
dimethoxy acetophenone
o-phenyl phenol
tetramethyl benzene
trichloropropane
dichloroiodomethane
bis-(2-ethoxy ethy) ether
chloroiodomethane
Acetylene chloride
isopropanol
chloroethyl ether
4,6-dinitro-2-aminaphenol
dioctyl adipate
docosane
eicosane
ethanol
ethyl benzene
cis-2-ethyl-4-methyl-1,3-dioxolane
o-ethyl toluene
heptachlor
1,2,3,4,5,7,7-heptachloronorbornene
hexachloro-1,3-butadiene
hexachloroethan
2-hydroxadiponitrile
isodecane
isoborneol
isopropyl benzene
methyl ester of lignoceric acid
methanol
methyl benzoate

2,4-dichlorophenol
1,3-dichloropropene
diethyl benzene
m-ethyl toluene
geosmin
o-methoxy-phenol
methyl tetracosamoate
piperidine
simazine
3,5,5-trimethyl-bicyclo-(4,1,0)-heptene-2-one
p-xylene
butachlor
dicyclopentaciene
pentachloroethane
2,3-dihydroindene
methyl benzothiophene
ethyl hexanol
ethyl acetophenone
2,6-di-t-butyl-4-methylphenol
butyl benzene sulfonamide
isocyanic acid
trichloropropene
chloral
bromomethane
chloropropane
bromotrichloroethylene
biphenyl
diethyl ether
2,6-dinitrotoluene
dipropyl phthalate
n-dodecane
endrin
ethylamine
2-ethyl-n-hexane
trans-2-ethyl-4-methyl-1,3-dioxolane
guaiacol
heptachlor epoxide
hexachlorobenzene
hexachlorocyclohexane
hexadecane
indene
isophorone
isopropenyl-4-isopropyl benzene
limonene
methane
2-methoxy biphenyl
methyl benzothiazole

methyl biphenyl
methyl chloride
2-methyl-5-ethyl-pyridine
methyl naphthalene
methyl phenyl carbinol
methyl stearate
naphthalene
nitrobenzene
octadecane
octylchloride
pentachlorophenol
pentane
phenyl benzoate
propanol
propyl benzene
1,1,3,3-tetrachloroacetone
tetrachloroethane
toluene
trichlorobiphenyl
1,1,2-trichloroethylene
2,4,6-trichlorophenol
1,3,5-trimethyl-2,4,6-trioxo-
  hexahydro-triazene
vinyl benzene
3-methyl butanol
methyl ethyl ketone
methyl indene
methyl palmitate
2-methyl propanal
methylene chloride
nitroanisole
nonane
octane
pentachlorobiphenyl
pentadecane
pentanol
phthalic anhydride
propylamine
1-terpineol
tetrachlorobiphenyl
tetrachloroethylene
trichlorobenzene
1,1,2-trichloroethane
trichlorfluoromethane
n-tridecane
triphenyl phosphate
n-undecane
xylene

## TABLE 1-IV-2

### Pesticide Chemicals Identified in Drinking Water Active Ingredients [94]

acenaphthylene
acetic acid
aldrin
atrazine
(de-ethyl)atrazine
bromoform
carbon disulfide
carbon tetrachloride
chlordane
chloroform
DDE
DDT
1,4-dichlorobenzene
dichlorethyl ether
dieldrin
4,6-dinitro-2-aminophenol
endrin
heptachlor
heptachlorepoxide
1,2,3,4,5,7,7-heptachloronorbornene
hexachlorobenzene
hexachlorocyclohexane
isophorome
naphthalene
pentachlorophenol
2,4,5-trichlorophenol

## TABLE 1-IV-3

### Non-Active Ingredients of Pesticide Formulations Identified in Drinking Water [94]

acetone
benzene
benzoic acid
camphor
chlorobenzene
o-cresol
dibutyl phthalate
dimethyl benzene (xylene)
2,4-dimethyl phenol
dimethyl phthalate
dimethyl sulfoxide
ethanol
hexachloroethane
limonene
methanol
(3-methyl-2-butanol)
methyl chloride
methyl ethyl ketone
methyl naphthalene
(methylated naphtalenes)
methyleve chloride
nitrobenzene
pentane
propanol
1-terpineol
tetrachloroethane
tetrachloroethylene
toluene
(1,1,1-trichloroethane)
1,1,2-trichlorethylene
trichloroflurowethane
xylenol

ingredients should not be considered comprehensive not only because of the lack of information on degradation products but also because of the possibility of the presence of unreacted pesticide raw materials. In addition many of the pesticide ingredients are also potentially derived from industrial, medical, and natural environmental sources.

It should not be inferred from this correlation presentation that the presence of pesticide chemicals and/or their degradation products in drinking water is explained by pesticide pollution of groundwater nor is the inference intended that the presence of these chemicals in drinking water does or does not lead one to the conclusion that they can be expected to be found in groundwater because of the characteristic flow patterns which relate groundwater and surface water.

## C. Laboratory Testing Procedures for Pesticides

There is a definite need in some areas for laboratory work to supplement the statistical data available. This is especially true in areas where edaphic and hydro-geologic factors are unique and conducive to pesticide transport into groundwater. Areas where data is marginal but show a need for further investigation should be sampled.

Analytical methodology for determination of pesticide residues and their metabolites and degradation products in environmental samples is in a state of constant development with rapid advances in analytical chemistry and instrumentation. There are several analytical methods available for pesticide residue analysis. At present, the most accurate and most advanced method available is gas-liquid chromatography. In the discussion of laboratory analysis, gas chromatography will be considered as a prime tool for pesticide residue analysis. If and when analysis warrants other methods to supplement gas chromatography, these more suitable methods should be employed.

All methods and procedures must follow the procedures described and published in the Association of Official Analytical Chemists (AOAC) [23]. The Food and Drug Administration, Environmental Protection Agency, and the Agriculture Research Service of the USDA all follow the AOAC. By strictly following the methodology of AOAC the data obtained will be within the limits and variables of data published by the above mentioned agencies. The procedures for processing and analyzing samples are given in the AOAC manual. Laboratory testing procedures are highlighted below.

Gas Chromatography. It is necessary to use preparative thin layer chromatography to separate and isolate pesticide residues from other contaminants. A pesticide residue separated from other contaminants should be analyzed using gas-chromatography equipped with electron capture detectors for its quantitative determination.

Injection technique and injection is one of the important starting functions of the gas chromatographic analysis. It is important that both standard and sample solutions be handled in precisely the same way in order to minimize errors caused by variable response of the instruments. It is also important that sample injection be carried out at least twice, as should be standard, to minimize errors.

Only glass columns should be used since they minimize decomposition. These columns must be conditioned at an elevated temperature before use. All columns will be standardized with various standard samples to check their efficiency and reliability.

Electron capture detection with a tritium source should be employed since these types of detectors are most accurate. When necessary, the tritium foils can be changed easily.

The areas under the peaks of the sample graphs and the standard graphs must be calculated in an identical manner so as to minimize measuring errors.

There is probably no need for nitrate determination in the laboratory. Sufficient published data is available at present to define and assess the problem.

Time and Temperature. Samples should be analyzed as soon as they are received in the laboratory. This will minimize physical and chemical changes that may occur. A waterless sample must be stored below 0°C in airtight glass bottles. Since light has an effect on pesticides and they do degrade under exposed light, samples must be kept in the dark and in amber colored glass bottles. It is necessary to avoid plastic or metal containers for storing samples, since they affect the pesticide concentrations or cause contamination. The caps used on the amber storage bottles should be equipped with teflon liners to prevent contamination.

Extraction Methods. A standard method of extraction should be employed to get the sample free from water and soil particles. Standard techniques such as blending or tumbling of the samples and solvents for rapidity and ease of handling should be employed. A mixture of relatively polar and nonpolar solvents has to be employed to get a thorough extraction of the pesticide residue.

Cleanup Procedure. It is necessary to use the standard cleanup procedure before GLC analysis. This should be done for two reasons. First, a cleaned sample will give specificity and ease of analysis, and secondly it will prevent undue contamination of gas chromatograph injection ports, columns, and detectors.

## V. ECONOMIC IMPACT OF GROUNDWATER CONTAMINATION ABATEMENT

### A. Introduction and Overview

The approach which is proposed to the evaluation of the economic effects of the regulation of groundwater contamination is related to cost-benefit analysis. This interconnection is important for two reasons. One is the legitimacy conferred on the suggested procedure through its compatibility with the generally-used and officially-suggested cost-benefit tool.* The second reason is that the cost-benefit framework is a useful one for clarifying the assumptions underlying the suggested economic impact analysis. Explanation of these interrelationships and assumptions should therefore introduce the economic evaluation of the regulation of groundwater contamination.

### B. Cost-Benefit Analysis

Cost-benefit analysis is the generally-accepted current practice used for the economic evaluation of public programs. As Mishan argues, cost-benefit analysis is not fundamentally different from the accounting for profitability employed by a private firm when considering an investment in the production of goods or services. Rather, the same sort of question is being asked about a wider group of people--who comprise society--and this question is being asked more searchingly. Instead of asking whether the owners of the enterprise will become better off by the firm's engaging in one activity rather than another, the economist asks whether society as a whole will become better off by undertaking this project rather than by not undertaking it, or by undertaking, instead, any of a number of alternative projects [36].

*Senate Document 97 encourages the use of cost-benefit analysis in public decision-making.

A critical part of any economic evaluation is the careful delineation of the relevant costs and returns. James and Lee categorize the benefits and costs associated with water resource planning [48]. In addition to the (a) tangible primary benefits gained directly from project-produced goods and services--examples are irrigation water and flood control--James and Lee categorize benefits as (b) tangible secondary, including gains accruing to output-receiving and input-providing industries interrelated with the directly-affected industry groups (c) tangible employment benefits (d) tangible public benefits and (e) intangible benefits. Tangible employment benefits are the new jobs created to construct, maintain or operate the project. Tangible public benefits include such often serendipitous gains as economic stabilization, income redistribution, and regional development.

## C. Intangible Benefits

Intangible benefits are consequences which cannot be assigned market value and which must be evaluated on a judgmental basis. Examples are the saving of life, improvement of health and the preservation of a desirable environment. Because these benefits involve value judgments, authors like James and Lee typically have less to offer about assessing them.

The above list of benefits shows the disadvantages of standard cost-benefit analysis for the assessment of the regulation of groundwater contamination. The benefits from such regulation are primarily intangible. They are also future-oriented. Groundwater typically moves slowly and is contaminated as a result of a long-term and gradual process. Once contaminated, nature's ability to cleanse the water is also slow (or even non-existent). This long-term situation means many of the most significant benefits from regulation of contamination accrue to future populations rather than to the current society.

Intangible benefits from maintaining pure groundwater are quite complex as well as very important. Economists like Weisbrod, Cicchetti, Freeman, Aaron and Fisher have identified at least four different "option values" for such forms of regulation. One of these, "option demand," is the value to individuals of having future access to a resource for economic uses. A second option value, "existence demand," is the demand of people who do not ever plan to use a resource, but who derive value from knowing it is preserved in its natural state. "Bequest demand," the third option value, is a derivative of option demand in which individuals wish to guarantee the option of using a resource for their heirs. Finally, there is "safety or hazard-aversion demand" from individuals who want to avert the risk of damage to their health.

All four option values result from the regulation of groundwater contamination. However, it is doubtful these values could ever be separated empirically, much less assigned a quantitative value. Furthermore, if one were to attempt to measure the various benefits as outlined by James and Lee, regulation of the contamination of groundwater would usually end up with a negative quantitative benefit value and a set of qualifying statements. Such a statement of benefits runs a risk of misinterpretation by anyone who does not read the report with care.

## D. Economic Impact Analysis

Negative benefit values do not invalidate cost-benefit analyses, but they do make such analyses awkward to handle. Consequently, economic analysts often shift away from cost-benefit analysis in such cases, and use economic impact analysis instead. Economic impact analysis starts with the a-priori presumption that the benefits are great enough to justify the public program. The goal of the analysis becomes the assessment of the costs of the program. Costs are not restricted to the direct and associated costs of the project's construction as they are in cost-benefit analysis. Rather, costs are defined to be the costs of cost-benefit analysis plus any quantifiable negative benefits. A major purpose of doing an economic impact analysis is to allow the initial assumption of the worthiness of the public program to be re-evaluated via a more informed judgment.

It is suggested here, and later in the "plan" section, that economic impact analysis best suits the economic analysis of the regulation of groundwater contamination. Such an analysis provides a suitable analytical context which is consistent with cost-benefit analysis and which is clear in interpretation. The framework of the approach emphasizes the central and a-priori nature of the judgment made about the intangible benefits and it encourages the re-evaluation of this judgment.

In the suggested economic impact analysis, costs would be defined as primary and secondary. Primary costs would be those incurred by the directly-regulated firms or households in complying with the regulation. Secondary costs are the negative secondary, employment and public benefits expressed as positive quantities. Any positive tangible benefits would, of course, be subtracted from these secondary costs.

The costs used in the impact analysis would be expressed as marginal values. Only the increase due to the introduction of the regulatory program would be measured. This allows the cost to be viewed as an impact. Also, it often simplifies the technical derivation of the cost coefficients.

## E. Primary Costs

Some of the techniques which could be used to measure primary costs at the firm or household level are partial budgeting, mathematical programming and economic engineering analysis. These techniques have a comparative advantage over other econometric methods at this level of dis-aggregation. Partial budgeting has the additional advantages of simplicity and unexpensiveness; however, its use depends on the availability of good accounting data. Mathematical programming can yield the same type of answers as budgeting plus additional results, but this more formal method is better suited for optimizing returns than for assessing impacts. Economic-engineering--called unit operation analysis by engineers--has an advantage whenever the costs of new productive enterprises are needed and the necessary accounting data is not available.

## F. Secondary Costs

Primary costs would have to be determined at the firm or household level and then aggregated to a regional level by using firm and household distributions. Secondary costs can be measured at the regional level via such techniques as input-output analysis, economic base analysis, social accounting techniques or by consumer and producer surplus measures of social welfare. Input-output analysis and economic base analysis focus on the costs incurred by industries that are economically linked to the regulated firms and households. The consumer-surplus oriented method focuses on the impacts on final consumers and on the suppliers of labor. All of these more formal methods are time-consuming, expensive and data-demanding. Yet they do not always incorporate all the secondary cost factors. As a consequence, they should be used only when a particular secondary cost is so significant that careful formal measurement is necessary.

The inter-relationships of the various measurement techniques will be more clearly specified in the tasks outlined later. It should be noted, however, that these tasks stress a careful and sometimes elaborate delineation of which primary and secondary costs are important as the quantification of a particular cost. Also, the proposed tasks stress simplicity of measurement, whenever possible, with the more complicated and expensive methodologies relegated to a back-up role. The keynote criterion of the proposed procedure is a uniformly accurate measurement of all significant costs. Such an approach should adequately serve the need for an economic evaluation of the regulation of groundwater contamination.

## VI. GROUNDWATER FLOW MODELS

### A. Introduction and Overview

Porous soil media is a complex matrix. Such a matrix may be viewed as a solid body with irregular interconnected voids. These interconnecting voids or pore channels are of primary interest in understanding the flow of miscible fluids in porous media. There are two approaches to the study of flow through porous media; the investigation of the particular porous media matrices that exist in nature, or the mathematical modeling of various types of matrices. Experimentally, the investigations would be limited to a small number of different porous media matrices; with theoretical model studies many different possible porous media structures could be investigated. However, the validity of the theoretical model must be assured through experimental verification.

Experimental techniques have been carried out to a high degree of refinement. Generally, a given substance is injected into the medium, and then the medium is sampled at various depths by cutting into it or extracting liquid from it for analysis. Theoretical modeling includes two distinct approaches (a) the deterministic model, and (b) the probabilistic model. The deterministic model is based on the solution of the basic differential equations for viscous fluids subject to dispersion and adsorption. The probabilistic models on the other hand concentrate on the statistical character of the porous media. The present state of the art of analytic - numerical methods for solving particular flow problems in porous media flow is to solve a set of coupled nonlinear partial differential equations with appropriate boundary and initial, etc. conditions.

In dealing with the movement of pesticides and nitrates from the soil surface down to the water table one must look at flows in the unsaturated region as well as flows in the saturated region. The unsaturated region consists of the layers overlying the groundwater table; in this region the soil pores are filled by two materials - water and air. Water movement in these layers consists of three phases -solid mineral grains, fluid water and gaseous air. The transport of water is more complicated in this region than it is in the saturated region (region below the water table) where the soil pores are completely filled with water.

## B. Unsaturated Flow

In the unsaturated region the infiltration process is a complex phenomenon. It consists of a hydraulic transfer of water, accompanied by extraction, and subsequent retention, of liquid by the sediment as the infiltrating liquid passes through it. For example, the water retention in gravel is negligible, while in sands the retention is due primarily to capillary action. In clays, however, the retention, which is essentially an osmotic pressure mechanism, is very large. The shrinkage cracks in a dry clay result in large amounts of water being transmitted. This lasts until the dry matrix has swelled and closed up, at which time the clay ceases to transmit appreciable amounts of water. From these considerations it appears that sediments or soils consisting of gravel, sand and silt are, in addition to fissured rocks, make up the principal soil formation capable of transmitting substantial volumes of water and contaminants into groundwater basins.

As stated earlier, the mathematics of flow in the unsaturated media is extremely complicated. In only a few cases have solutions been obtained. These solutions were obtained using one-dimensional, two-dimensional, and simplified models. Little is known of the adsorption mechanism of pesticides on soil matrices. Experimental studies indicate various amounts of CH are leached from different soils. In summary, knowledge of moisture movement in the unsaturated zone is not advanced to the stage where one can accurately predict transient moisture changes under actual field conditions; complete models that accurately predict migrations of various pesticides and nitrates in the unsaturated zone have not been fully developed.

## C. Saturated Zone

The theory of dispersion of miscible fluids in porous media has received considerable attention in recent years. Interest in dispersion has resulted from water quality considerations of waste disposal operations, sea water intrusion and seepage from canals into aquifers.

Hydrodynamic dispersion or miscible dispersion is a spreading phenomenon. Experiments show that when a flow containing a certain mass of solute (known as a tracer) is moving, the tracer usually spreads and occupies an ever increasing portion of the flow domain, beyond the region it is expected to occupy according to the average flow alone. The mixing of the tracer mass with the remaining portion of the flowing liquid is a transient, irreversible process. Hydrodynamic dispersion is the macroscopic outcome of the actual movements of the individual tracer particles through the soil pores and also the outcome of various physical and chemical phenomena that take place within the pores.

The two basic transport phenomena involved in dispersion are convection and molecular dispersion. The two basic elements of convection or mixing are the flow (variation in local velocity, both in magnitude and direction) and the geometry of the pore system. Molecular dispersion is a mass transport phenomenon resulting from variations in the tracer concentrations within the liquid phase. The interaction between the solid surface of the porous matrix and the liquid may take several forms: adsorption of tracer particles on the solid surface, deposition, solution, ion exchange, etc. [38]. All of these phenomena, as well as chemical reactions within the liquid, may cause changes in the concentration of the tracer in the flowing liquid.

Because of the complexity of the dispersion-adsorption phenomenon in porous media, no general model has been formulated and solved. Solutions to various specific miscible displacement problems in porous media have been obtained by a number of investigators. Common to most of these studies is the basic assumption that the concentration at one boundary is in the form of a step function; that is, the concentration of the tracer to be introduced at one boundary changes instantaneously from zero to some predetermined value and is maintained thereafter (conservative model). In addition, most models assume that convection and dispersion are the principal factors in mass transport while other mass transport mechanisms are considered insignificant and therefore neglected.

The model studies which have been performed by various investigators can be placed into one of two categories: (a) dispersion with no adsorption, and (b) dispersion with adsorption. A brief summary of each type of modeling is given below.

## D. Dispersion With No Adsorption

Some of the early analytical solutions for longitudinal dispersion within a semi-infinite non-adsorbing porous media were obtained by Ebach, et al (1958) and Ogata, et al (1961). In both cases, a steady undirectional flow was assumed; the Ebach study assumed an input concentration that is a periodic function of time while the Ogata study considered the input concentration to be a constant. Hoopes, et al (1965) investigated the problem of dispersion in radial flow from a fully penetrating well operating in a homogeneous, isotropic confined aquifer. The study was directed primarily at dispersion from injection wells where the solute was non-adsorbing. Shamiz, et al (1960) obtained analytical solutions for longitudinal dispersion in a semi-infinite non-adsorbing layered medium. In their model, the flow was assumed to be perpendicular to the layers of longitudinal dispersions and parallel to the layers for the lateral dispersion case. In both cases the input concentration was assumed to be constant and adsorption was neglected. Bruch and Street (1966) investigated the flow in a semi-infinite non adsorbing porous media subject to longitudinal and lateral dispersion. As in the previous studies, it was assumed that there is steady undirectional flow which was subject to a constant concentration input.

## E. Dispersion With Adsorption

Nielsen, et al (1962) presented several examples of breakthrough curves in which interaction between the liquid and the solid phase has taken place. Several theoretical models have been suggested for dispersion with adsorption. Lindstrom, et al (1967) examined various solutions to the dispersion equation subject to linear adsorption under input conditions of continuous flux and plug type. Ogata (1964) obtained an analytical solution to the one dimensional dispersion equation subject to linear adsorption. Similar solutions were also obtained by means of the integral transform method by Cleasy and Adrian (1973). Banks and Ali (1964) presented an analytical solution to the dispersion equation subject to a linear adsorption isotherm. The flow was considered to be steady and one-dimensional under a constant concentration input. The case of non-linear adsorption was also investigated subject to no dispersion. Gershon, et al (1969) studied the effects of boundary conditions of various models on tracer distribution in flow through porous media. A solution for one-dimensional dispersion subject to a semi-infinite adsorpting porous media was presented.

Numerical solutions of the dispersion equation for different adsorption equilibriums was reported by Lai, et al (1972). Solution to the one dimensional dispersion equation subject to non-linear adsorption was given by Tagamets, et al (1974), and by Gupta, et al (1973) for a bilinear rate of adsorption. Solution of the dispersion equation with adsorption was also reported by Rubin (1973). A summary of some analytical solutions to the dispersion equation is given by DeWiest (1969) and Ogata (1970).

### F. Summary of Dispersion Models

In general, the available analytical solutions of the dispersion equation are for simple one dimensional flow with constant concentration input. In all of these cases adsorption has been neglected or assumed linear. The available numerical techniques provide approximate solutions for dispersion with non-linear adsorption in one dimensional flow. All of the above cases are ideal, i.e. homogeneous, isotropic soils, constant initial concentration and well defined adsorption isotherms. Unfortunately, conditions in nature cannot be duplicated by the models; soils are not homogeneous and isotropic, concentration varies with time and space, and the adsorption isotherms of many pesticides are not well known.

### C. Regional Models

A physical-chemical model for predicting the movement of contaminants in an isothermal groundwater system in which there are no chemical reactions was developed by Bredehoeft and Pinder [5, 6]. The mass transport equation and the equation of motion have been coupled and solved numerically for a saturated groundwater system.

The authors tested their model by analyzing the movement of contaminants in the principal aquifer at Brunswick, Georgia [59, 60]. The particular contaminant studied was salt water contamination (chloride) and the model was used to predict future chloride distributions. The model was calibrated using data available due to extensive geohydrological investigations conducted by USGS at Brunswick. The use of this model to predict changes in ground water quality is limited. The complete physical - chemical description of moving groundwater must include chemical reactions in a multicomponent fluid and requires simultaneous solutions of the differential equations that describe the transport of mass (including dispersion, adsorption) momentum and energy in porous media. Pinder [55] used the Galerkian method in conjunction with the finite element method to simulate the movement of groundwater contaminants. The mathematical model was used to simulate the movement of a plume of chromium contaminated groundwater on Long Island, N.Y. The two dimensional model considered porosity and hydrodynamic dispersion to be the principal aquifer properties affecting mass transport. Values of longitudinal and lateral dispersion were estimated based on tests conducted on similar material due to lack of actual data. Adsorption was neglected in this study. Calibration of the model was based on historical record of chromium distribution and was used to predict the location of the plume in future years. The model requires extensive data and is limited to cases where the point where the effluent concentration enters the aquifer is known.

In 1974 a digital computer program [22] was developed to estimate concentration of total dissolved solids (TDS) of extracted water from a multiaquifer groundwater basin. The model considered salt input from natural sources due to man's uses of water: domestic, industrial, and agricultural. The model was tested on the Santa Clara - Calleguas area in Ventura County, California. That area was selected because a water quality model was already available for the area and could be used to simulate groundwater movement.

The quality model considers six inflows such as rainfall infiltration, percolation, etc. and three outflows: subsurface outflow, extraction and consumption by phreatophytes. The model does not account for chemical reactions, adsorption of dispersion. It is basically a tool for management to predict TDS concentration subject to different inflow parameters.

During 1974 the U.S. Geological Survey (USGS) [61,53] completed a study wherein a conservative model was developed. The linear mathematical model used in the USGS study is an idealized representation of the San Juan Valley groundwater basin. It describes in concise quantitative terms the response of the groundwater system to various conditions of stress or development. Once such a quantitative response has been obtained, the model can be used to facilitate an understanding of the hydrologic system and aid in determining how climate, geology, and man influence the groundwater basin. The model was developed according to the theory and analytical approach developed by Pinder and Bredehoeft [5], (1968) [6].

In order to use this mathematical model as a predictive tool it must first be calibrated. Model calibration is accomplished by combining, in the model, hypothetical distributions of transmissivity and specific yield values with sets of known or estimated groundwater flow conditions. The correct, or calibrated, combination of aquifer parameters and flow conditions is determined when model-generated water levels approximate historical water levels within some predetermined limit of accuracy.

Recently the Agricultural Research Service of the USDA published an Agricultural Chemical Transport Model (ACTMO) [25]. The objectives of this model are to predict the concentration and amount of the chemical in the runoff water and in the sediment at the watershed outlet, and to predict the location and concentration of chemicals that are leached and moved spatially through the soil of the watershed. The model includes such management options as the time, rate, and type of chemical applied, changes in crop pattern, and tillage practices. To facilitate application, topographic, soil, and land use maps of the watershed are used to estimate model parameters. The model's authors assume that published data from the field and laboratory can be used for estimating the chemical interaction with the soils and water.

The model is divided into three submodels: a chemical, an erosional, and a hydrological submodel. The erosion submodel receives data from the hydrology submodel while the chemical submodel receives data from both the hydrological and erosional submodels. This separation facilitates the interchange of other chemical, erosional or hydrological submodels and modifications. Objectives of the initial effort were to achieve an operating version of ACTMO for certain limited conditions.

Unfortunately, ACTMO which is a dynamic model, is aimed primarily at surface water runoff from a specific farm. However, it could be modified to reflect the groundwater recharge problem, and by manipulating and adding parameters, it could be used over large section of soil regions.

A model, called the Pesticide Transport and Runoff (PTR) Model [12] was developed by the EPA. This model is primarily a surface model, but like ACTMO it gives results adaptable to groundwater needs. Four pesticide storage zones with assigned depths within the soil profile are assumed: surface zone, upper zone, lower zone, and groundwater zone. The assumed zone depths are necessary to specify the mass of soil involved in the pesticide-soil interactions.

The PTR Model estimates the loss of pesticides from the land surface by simulating the mechanisms of surface runoff, sediment loss, pesticide adsorption-desorption, and pesticide volatilization and degradation. There are various loss mechanisms and submodels included within the PTR Model. The hydrologic submodel is responsible for the determination of surface runoff and soil moisture storage. The sediment loss submodel estimates sediment production from the land surface based on input rainfall and surface runoff provided by the hydrologic model. The division of applied pesticide among the various phases (adsorbed, dissolved, and crystalline) is determined by the pesticide adsorption-desorption submodel. This submodel, in conjunction with the hydrologic and sediment loss submodels, determines the amount of pesticide removed from the land surface by surface runoff and sediment loss. This model also considers the loss of pesticides by volatilization and degradation.

Another recent model [14] developed for the EPA describes pesticide movement through soils. In this work a numerical simulation procedure for describing the simultaneous transport of water and adsorbed and nonadsorbed solutes was developed and evaluated. The combined effect of convection, adsorption-desorption, and dispersion (diffusion and mechanical dispersion) were considered as well as a correction for numerical dispersion in the finite difference solution of the solute transport equation. Experimental laboratory and field data were used to evaluate the suitability of the two numerical solutions to describe the movement of each phase. Adsorption and desorption was also studied for several herbicide-soil systems. Several adsorption models were considered and evaluated in the solute transport equation. However, a numerical solution has not been developed and tested for simultaneous transfer of water and adsorbed solutes in a soil.

It appears that, given reasonable time to develop or modify subsections from existing models, a working model could be developed which would describe the percolation of nitrates and/or pesticides through various soil types and into groundwater. Although such a model can be developed, there are two obstacles which potentially limit the usefulness of the model: (a) the amount of data available for input into the model; and (b) the surface area over which the model can be applied. The PTR and ACTMO models can now characterize only a few acres of surface, which indicates the degree of difficulty still to be met in modeling larger areas.

The EPA laboratory at Athens, Georgia, is developing a water basin study using an area of approximately twenty square miles in Iowa [103]. This region will be instrumented and modeled for surface and subsurface runoff evapotranspiration, rainfall, crop cover, soil porosity and moisture, pesticide (and fertilizer) applications, rates of denitrification, etc. An estimate will be made as to how much water percolates through the soil as part of the materials balance, but a measurement of the effects on groundwater as such are not projected at present. It would seem feasible that this multiyear study could be modified to include considerations of groundwater, and the model extended to include this dimension. Putting this project in perspective, one of the intents of this study is to give the EPA and the manufacturers of pesticides a "standardized" method for calculating the potential impact of a pesticide on surface waters before registration is granted.

The U.S. Geological Survey and certain contracting firms have developed models [60] for the U.S. Energy Research and Development Administration (formerly the U.S. Atomic Energy Commission) which characterize the transport of radioactive and chemical wastes from buried materials. Reeves and Duguid [16,58] have developed a two-dimensional transient model for water movement through saturated-unsaturated porous media which can cope with multi-layered geologic formations. This model uses the Galerkin finite-element method.

With these point source models available, it appears feasible that with additional submodels included, a feedlot (or septic system) could be adequately modeled to estimate groundwater impacts.

Many other models have been developed and come to our attention, but an extensive evaluation of each model at this point is not in order. Such an effort, however, has been assigned by EPA (Ada, Oklahoma) to the Commission on Simulation Modeling of the Scientific Committee on Problems of the Environment, headed by Drs. Frenkiel and Munn [64]. This project, titled "Evaluation of Existing Groundwater Basin Management Models," is funded in part by EPA under project control number R803713-01. This project is directed to the EPA program catalogue number and title 66.505 Water Pollution Control-Research Development and Demonstration. This year long effort is expected to be completed in late Spring-early Summer of 1976.

The objective of this study is to evaluate existing groundwater basin models in order to judge the state of knowledge and state of the art in this complex art-technology. The intent is to provide guidelines for future modeling development work to insure a sound and logical baseline. Indirectly, the project may provide guidelines for optimizing the design of monitoring networks.

It is strongly suggested that there be a high level of interchange between this committee and the EPA task force concerned with groundwater modeling efforts in order to more rapidly implement the findings of other groups already working in this field.

# THE IMPACT OF INTENSIVE APPLICATION OF PESTICIDES AND FERTILIZERS ON UNDERGROUND WATER RECHARGE AREAS WHICH MAY CONTRIBUTE TO DRINKING WATER SUPPLIES

## Section 2

## Approaches For A More Detailed Investigation

### I. INTRODUCTION

This study has considered major agricultural practices with regard to their possible adverse impact upon groundwater recharge areas. Information has been gathered from many sources including literature search, interviews, personal communications and review of other related studies and investigations. In the light of current knowledge, it is apparent that all of the complexities and interrelationships of the many facets of groundwater pollution are not yet fully comprehended.

Therefore, a set of tasks has been formulated which illustrates an approach to better understand the total problem and would provide a basis for judging the need for measures of abatement and control. These tasks and any further work on the problem will be considered within the context of competing priorities for fulfilling the charges under the Safe Drinking Water Act.

These tasks, which could be carried out in a period of about fifteen months, have been carefully defined to avoid duplicating efforts completed or in progress elsewhere. A considerable effort is already underway at various institutions pertaining to the broad topic of intrusion of toxic substances into groundwater from the use of such chemicals and also from the operation of feedlots and septic systems. The related problem (not dealt with in this study) of saline buildup, in connection with irrigation practices, is also under extensive investigation. The results of these studies will provide inputs to the various tasks described here below.

Some tasks do complement work already carried out, but are included here in order to broaden or fill-out these other projects. Tasks which require very long term efforts, even though potentially valuable, have not been included; also projects of marginal payoff have been omitted. A set of econometric tasks, in which the costs and rewards of optimal corrective measures would be evaluated, illustrates an approach to defining the financial impact and/or justification of any recommendations ultimately considered by the Agency.

Some of the proposed tasks are common to, or impinge upon, topics under consideration, whereas others are germane only to specific components, such as pesticides, fertilizers, feedlots, etc. The presentation, therefore, is structured into "activity streams" (Figure 2-I-1) in which the investigations may be conducted concurrently. Four major subject areas are considered:

1. Nitrates
    - o Fertilizers
    - o Feedlots
    - o Septic Tanks
2. Pesticides
3. Economic Impacts
4. Modeling and Simulation

The "general" activity stream (Tasks G-1, G-2, G-3, et seq) is designed to generate basic information relatable to all three sources of nitrates and to pesticides. A separate activity stream is then pursued for fertilizers (Tasks FR-1, etc.) feedlots (Tasks FE-1, etc.), septic tanks (Task S-1, etc.), and pesticides (Task P-1, etc.) and finally all five streams are brought together for the economic impact (Task E-1) and modeling (Task M-1) activities.

In the following pages, the objectives, scope and technical approach to each set of tasks are described. To support and illuminate these descriptions, a detailed discussion of each subject area and the present state of knowledge in each is given in a series of appendices to the plan.

## II. GENERAL

### A. Task G-1

Objective: To identify and map those areas of the country which may be vulnerable to groundwater contamination from agricultural practices.

Scope: The nation's systems of groundwater reservoirs are influenced by climate, soil characteristics, depths of impervious layers, water tables, and other factors. Those areas in which major productive aquifers occur, i.e., aquifer which can yield more than 50 gallons of water per minute to the public water supplies are to be located and identified, in terms of their vulnerability to contamination.

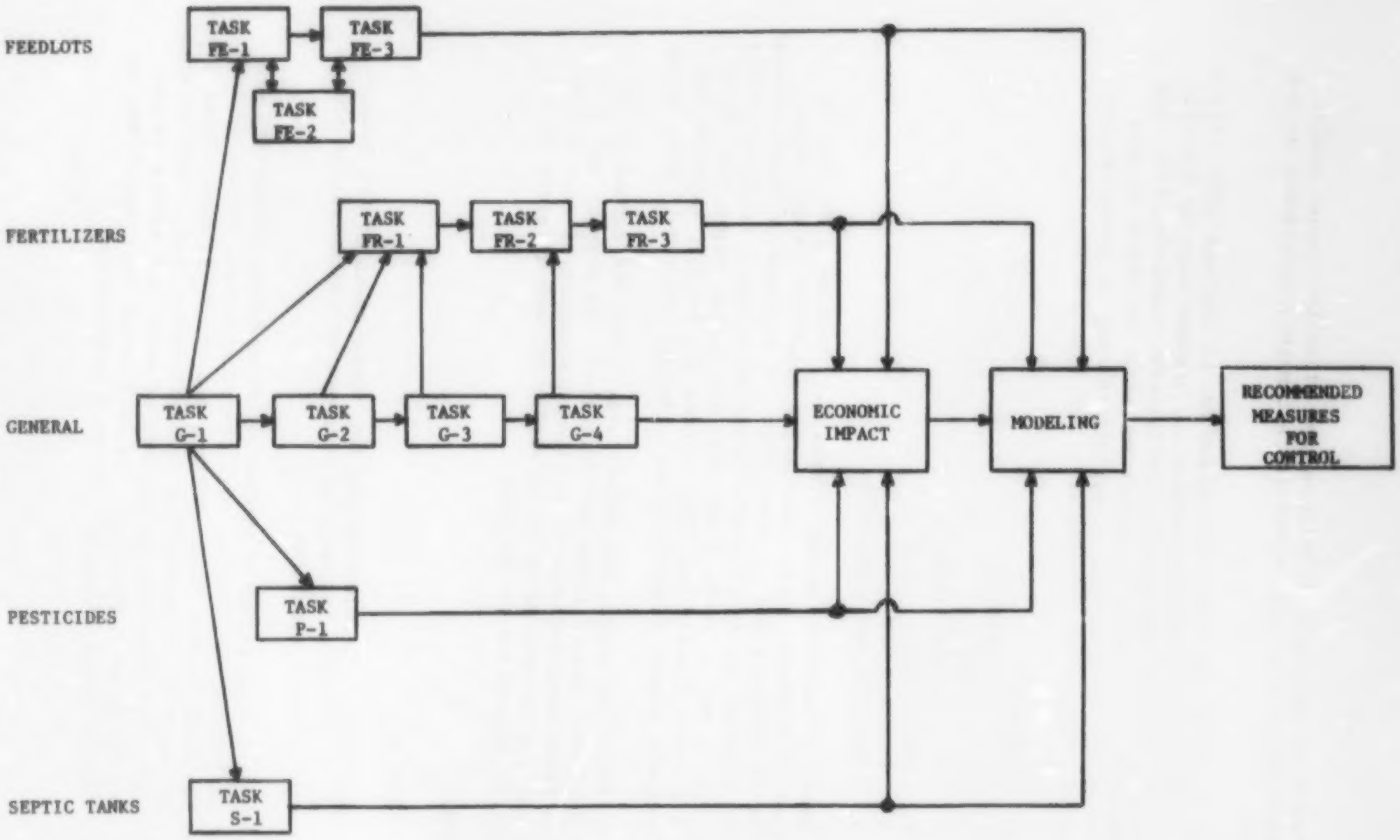
FEEDLOTS
FERTILIZERS
GENERAL
PESTICIDES
SEPTIC TANKS
TASK FE-1
TASK FE-3
TASK FE-2
TASK FR-1
TASK FR-2
TASK FR-3
TASK G-1
TASK G-2
TASK G-3
TASK G-4
TASK P-1
TASK S-1
ECONOMIC IMPACT
MODELING
RECOMMENDED MEASURES FOR CONTROL

Figure 2-I-1 Activity Streams

Approach: From data available through such agencies as the U.S. Geological Survey (USGS), State Water Resource Research Centers, U.S. Department of Agriculture (USDA), U.S. Environmental Protection Agency (EPA) and others, a map will be prepared to show those areas where public water supply is drawn from groundwater reservoirs which are most vulnerable to contamination by virtue of being overlain with thin or sandy soils, highly fractured rock or by having relatively high water tables.

B. Task G-2

Objective: To define and map predominant agricultural activities practiced in the vulnerable areas identified in Task G-1.

Scope: Agricultural activities on the land determine the nature and extent of possible groundwater contamination. The range of activities in areas of productive aquifers with vulnerable edaphic and geologic characteristics will be identified.

Approach: A map of agricultural activity regions will be superimposed on the vulnerable areas map prepared in Task G-1. This will enable the crop producing and cattle feeding areas of the country to be related to groundwater supply and the regimes of pesticides and fertilizer applications and feedlot operations to be determined.

C. Task G-3

Objective: Within the vulnerable areas, to compare available water quality data from productive aquifers with predicted values obtained from Tasks G-1 and G-2.

Scope: Groundwater quality data, while imcomplete, is available from several sources. These data can be used as a benchmark to measure the accuracy of the regimes used in Task G-2 for predicting groundwater contamination.

Approach: A review of groundwater data quality files for areas in which intensive agriculture is practiced within the vulnerable areas is a priority project task. Data of this type is available through the U.S. Geological Survey (USGS), state Water Resource Research Centers, U.S. Bureau of Census, U.S. Department of Agriculture (USDA), U.S. Environmental Protection Agency (EPA), Soil Conservation Service (SCS), state Agricultural Extension Services, Land Grant College's agricultural research programs, and U.S. Army Corp of Engineers.

These data will be compared to the effects of nitrates and fertilizers on groundwaters from known agricultural practices in the vulnerable areas, as calculated in the previous task.

### D. Task G-4

Objective: To determine whether or not "best" agricultural practices can be used to abate groundwater problems.

Scope: Up-to-date scientific knowledge and procedures are used in the management of many farms, particularly those operated as large corporate entities. The effectiveness of those practices, in areas of groundwater contamination, will be evaluated and compared to the less structured procedures used by the individual farm operator.

Approach: In each vulnerable area, an "economic" farm will be selected, if possible, and the procedures and extent of use and control of pesticides and nitrates on that farm determined. The groundwater quality of these areas will then be compared to areas in which no "economic" farm is operated. Soil, water tables, and geologic characteristics will be taken into consideration in the subsequent evaluations.

## III. NITRATES

### A. Fertilizers

#### 1. Task FR-1

Objective: To determine the degree to which nitrate contamination of groundwater is attributable to agricultural application of fertilizers. [It may be possible to estimate how much nitrate in groundwater derives directly from fertilizers and how much from plant decay, nitrogen fixation, animal wastes and septic systems by a technique* using isotopes of nitrogen which are indicators--to a degree--of the nature of the source.]

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*This technique has been developed at Washington University, St. Louis, Missouri.

Scope: The areas of investigation are limited to those in which there is intensive farming and high rate of nitrate fertilizer application. Regions with deep aquifers and low recharge levels need not be considered. Aquifers which can yield more than 50 gallons of water per minute to public water supplies are of primary concern.

Approach: It is recognized that nitrates usually percolate into soils at a greater rate during the winter months when plant uptake of nitrogen ceases, plant decay adds nitrogen to the soil, and groundwater recharge rates tend to increase. When assessing groundwater quality data, the time of testing needs to be determined, if it is obtainable. Data should be collected preferably in winter or early spring.

Areas of fractured rock overlain by a shallow soil mantle are areas of high hazard since nitrates readily pass through the porous fissures in such rocks as creviced dolomite, limestone and shale.

Areas of high water table (only a few feet below the surface) are less hazardous to groundwater from the nitrate point of view because the soil is in an anaerobic state (deficient in oxygen) where denitrification (nitrate may be converted to nitrogen gas) is promoted if carbonaceous material is present.

Nitrates do not quickly mix with the deeper levels of groundwater under conditions of laminar flow, but normally "ride on top" of the groundwater water layer for many months. In taking samples it is well to know if the sample was taken from the top of the aquifer.

With data obtained from G-1, G-2 and G-3, the following tasks will be carried out:

Task FR-1A. Prepare mappings of the agricultural areas of the country to show levels of nitrate above acceptable levels (choose several levels greater than 5 ppm, greater than 10 ppm, greater than 20 ppm, greater than 45 ppm and greater than 100 ppm) for different years of testing so as to indicate visually the increased level of nitrate pollution where it exists.

Task FR-1B. Correlate fertilizer application levels versus crop and tillage practices, climatic conditions and aquifer flow rate. This data will allow for estimation of nitrate concentration increases in the groundwater through the increase of fertilizer application rates. Other factors such as a change in the time of application, or the use of less soluble forms of nitrogen--such as urea--can then be studied as to their effect on nitrate leaching into groundwater.

Task FR-1C. The effort to study groundwater recharge must include some estimate as to the degree of recharge from local streams and ponds which are either high or low in nitrate.

Surface streams tend to recharge the aquifers (and the aquifers recharge the streams). Often, during the late summer, the aquifer recharges the stream more than the stream recharges the aquifer. Nitrates from the top of the aquifer pass to the stream. In the winter the aquifer is recharged by the stream carrying nitrates and other soluble substances into the aquifer.

A study of this balance will help to indicate the source of intrusion of toxic substances into the groundwater.

2. Task FR-2

Objective: To determine how farmers can control nitrate percolation into groundwater in those areas where groundwater nitrate problems have been traced to fertilizer applications.

Scope: In each agricultural region there are some farms that are operated on a scientific and cost effective basis. Some of these farms are operated probably in areas experiencing groundwater nitrate toxification problems. It is in these areas, where fertilizer application is suspected of being the primary contributor to this groundwater problem, that farms should be selected for study.

There should be strong similarity between each selected farm and the "control" farms in the area in topography and the crops grown. A number of farms should be selected, with preferably two or three in each area studied. A selected pair of farms in one area may be as much as 20 to 50 miles apart.

Approach: With data obtained from G-4, the tasks defined below will be pursued. In the event that this approach is successful, there will be a strong indication that an appropriate farm management training program would be beneficial. Also required will be effective research to determine the capacity of crops to take up nitrates (and other nutrients) from fertilizers and soils. Fertilizer applications could then be made in optimum amounts and at judicious times so as to minimize the leaching and runoff potential.

Task FR-2A. The first order of business is to set criteria and then to select and contact the farms to be used in the study. State or federal agricultural farms and previously studied farms can be included if they meet the criteria listed in the "Scope" above, but private operations will generally be chosen. Negotiations will determine the degree of cooperation (and the possible fee for the use of the farmer's time and facilities) which is required. It may be possible to incorporate additional funding into the study from interested state agricultural agencies and extension services, and Water Resources Research Centers of the State, USDA Agricultural Research Service, USGS, soil conservation service, and land grant college agricultural programs. In some instances the use of equipment and personnel from these sources may substitute for cash input to the study. For example, the state may provide the testing of water samples free.

Task FR-2B. A file of the farm characteristics will be made, consisting of: (a) a topographical map of the farm which will also show locations of fences, buildings, wells, septic tanks, etc. (b) the history of the farm extending back at least 5 years, preferably 10 years or more, including all pertinent data that will help in determining what factors contributed to the local groundwater quality. These data include, but are not limited to the following:

### DATA OUTLINE

- Cropping patterns and amounts planted
- Yields
- Fertilizer applications and types (include manner of application)
- Pesticide usage

- Tillage practices
- Building additions and other physical changes to farm such as pond construction or creek dams, etc. (include timing information)
- Livestock history
- Climatic factors affecting crop
- History of soils tests
- History of any drilling of wells (test, drinking, irrigation)
- Any practices which would affect groundwater (dump area for farm wastes, fertilizer and pesticide containers, etc.)
- Septic tank and outhouse locations and periods of use (installed or stopped usage)
- Other pertinent data such as water table levels, years when well was dry or low, etc.

(c) test the present farm wells for nitrate levels and drill test wells at judicious locations about the property to obtain edaphic, geological, and hydrological characteristics of the farm. Lysimeters should be placed where appropriate.

Nutrient and microbiotic matter in the soil, soil moisture, hydrologic conductivity, water quality in each of the wells placed on the property, etc. shall be recorded at least monthly. Precipitation, water runoff, temperature and humidity levels can be recorded automatically. The water runoff may be difficult to obtain due to topographical characteristics and may have to go unknown on some farms.

Task FR-2C. Record the farm activities that take place during the year of study, including but not limited to the following:

- Time of all activities
- Record of pertinent weather conditions
- Amounts of pertinent materials used

- Tillage of various fields (plowing, disking, etc.)
- Planting of seeds
- Fertilizer applications
- Irrigation water used
- Changes in livestock patterns
- Soils analyses
- Crop yields
- Pesticide applications
- Cutting of hay, alfalfa, etc.
- Changes in topographical features (e.g., new pond, or an old pond drained or serious erosion of an area)
- Dumping on spillage of fertilizers and pesticides on the farm property
- Dumping of wastes on the farm property
- Any other significant operations

Task FR-2D. Digest the data recorded and investigate for correlations between farming activities and the data developed on groundwater quality (nitrates and pesticide residues).

B. Feedlots

1. Task FE-1

Objective: To establish a method of standardizing animal waste analysis and research reporting.

Scope: Standardization will allow for a clear statement of any measurements or analysis techniques that may be required in future feedlot regulations as they apply to protecting groundwater from contamination (and as they apply also to runoff contamination). In order to compare research results and establish application rates there must be standardized data reporting.

Approach: Data on location of research by climate and soil characteristics will be made. The depth of impervious layers, water tables, and other pertinent information will be reported. This is necessary in that future regulations may require analyses of the quality and quantity of minerals percolating through the soil as a result of feedlot operations.

This approach can best be pursued by forming a team of experts in the field of animal wastes analysis and research. Using data provided from Task G-1, the team will carry out the following:

Task FE-1A. Review the work previously accomplished in the areas of animal wastes analysis and research. Consideration must be given to the various conditions under which data must be collected and the purposes for which it is recorded. It is recommended that analyses be expressed on a dry weight basis, except possibly for liquids of low solids content (approximately 1% or lower).

There must be a procedure established whereby data taken in various locations and under extremely different climatological, edaphic, geological, and hydrological conditions can be related. The important point of the work is that the method of analysis and reporting be standardized so that regulations can be written and enforced in a meaningful way.

2. Task FE-2

Objective: To assess the success of the various methods to control feedlot runoff and manures, particularly in relation to groundwater contamination. A secondary objective is to develop a set of criteria for required sizes for waste storage facilities and for maximum feedlot sizes and animal densities for specified control techniques used at sites in various regions of the nation.

Scope: During the past five years or so techniques for collecting and holding feedlot runoff and manures have been adopted at many feedlot locations. The effectiveness of these techniques must be assessed. This project cannot be entirely segregated from efforts to prevent runoff of effluents into streams and ponds which also recharge groundwater.

Approach: Investigate those feedlots which have been instrumented to determine the level of nitrate penetration into underlying soils, and ultimately into groundwater. Simultaneously select additional feedlots to be instrumented, which do not duplicate the above situations, which use alternative collection and storage techniques. This selection is to be made to represent varied feedlot design, size, manure types, soil and climatic conditions, geology, and hydrology. Beef and dairy cattle, hog, and poultry feed operations will be considered, with cattle operations receiving major emphasis.

This approach will be best accomplished by performing the following tasks:

Task FE-2A. Review available studies on projects which have analyzed certain feedlot designs for collecting and holding effluents and solids from feedlots. It is noted that many studies have been concerned primarily with preventing runoff into streams and ponds. Measurements of nitrate levels in nearby streams are usually available. Many studies have identified the percolation of nitrates into the soil at points within the feedlot and about the perimeter. The most significant data are those from measurements made during the winter and spring seasons when nitrate concentrations usually appear higher.

The review should be especially concerned with areas that include soils with shallow groundwater (15-50 feet) depth. Here nitrate concentrations in soils are important because leaching into groundwater is potentially high.

In humid zones the concentration of waste salts should be recorded and the degree of leaching determined. Where records exist on the quality of groundwater in the direction of flow away from the feedlot the dispersion pattern and amount of dilution should be calculated.

Task FE-2B. In areas where feedlot operations are located on permeable soils overlying shallow aquifers, the groundwater contamination levels need to be investigated more extensively. The feedlots to be tested for groundwater contamination are to be those in regions representing soil and manure types, geological, hydrological, and climatological conditions not covered by existing studies as identified in Task FE-2A. Where feasible, when existing studies have incomplete data, efforts to test for the additional necessary data should be made at these sites.

Tests should be conducted so as to obtain data which coincides with the standardization procedures being developed in Task FE-1. Since both tasks FE-1 and FE-2 will be in operation simultaneously, effective cooperation will be needed between the two Task groups.

The testing shall be performed around the feedlot perimeter and at locations where the groundwater flows down stream of the feedlot. Existing wells should be utilized when feasible, but test wells should be installed as appropriate. Testing should be done at several intervals during the year to observe seasonal variations.

Test wells should be drilled to a depth which will draw water samples from the upper levels of the aquifer. It is in this region that contaminants concentrate because of the minimal vertical mixing which occurs under conditions of laminar flow. Profiles of nitrate and salt concentrations in the soil should be obtained. Soil moisture, bio-oxygen demand (BOD), hydrological conductivity, and other parameters should be measured as required. In areas where the groundwater has not been contaminated, these data are invaluable in building a history for the feedlot region and feedlot design.

Testing of the soils and groundwater should be coordinated with testing programs presently being conducted by the EPA's R. S. Kerr Laboratories (Ada, Oklahoma), the U.S. Department of Agriculture, and the U.S. Geological Survey. Some of these programs involve in-house efforts and others are in connection with land grant schools and state water resource research programs.

Task FE-2C. The task force will continually synthesize data and project the outlook for the future with respect to feedlot designs, manure types, edaphic, geological and hydrological conditions. This perspective will provide the context within which to develop the understanding required for the design of sound regulations for groundwater protection.

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3. Task FE-3

Objective: To determine the degree of groundwater toxification resulting from recharge from animal waste applications which are occasioned by feedlot operation.

Scope: It is recognized that there are many means of disposing of animal wastes, including spreading, treating, refeeding, synthesizing, burning and so forth. This task is concerned with the discharge of wastes on lands after various levels of treatment in holding and treating ponds. This study is most concerned with the effects on groundwater toxification as a function of application rates, edaphic characteristics, climate, geology, hydrology and time of application.

Approach: The following tasks will be carried out:

Task FE-3A. A survey of areas where the application of animal wastes is affecting permeable soils with shallow groundwater (15-50 feet) will probably show that these conditions offer higher potential of groundwater contamination than areas that are arid. A survey of the nitrate levels in groundwater in these regions is required, using files from local well testing data. This data will often mesh with the data collected in Task FE-2 and there should be a close working relation between the two task groups.

Task FE-3B. Methods of application of animal wastes, as well as composition of the wastes, the amount and time of application, crop cover, climate, edaphic conditions and hydrology will be surveyed to determine which methods are applicable, and which are not, in identified regions and seasons.

In Illinois, for example, nearly all recharge to groundwater occurs between the first of November and the end of April, during periods when evapotranspiration losses are minimal, soil moisture deficiencies have been satisfied, and during periods when the ground is unfrozen. It would probably be inappropriate to apply animal wastes during this period, unless mitigating factors allow for winter applications.

Plant capacities for nitrogen uptake, and the optimum times and rates of application, should be assessed for the edaphic conditions existing at various feedlot areas. Much of this data will have to be gathered from the land grant colleges, state agricultural research services, extension services, and the USDA's Agricultural Research Service (Dr. Stanford, USDA, Beltsville). Minimal data is now available in this area.

These factors should be identified for all areas where waste spreading is conducive to groundwater contamination.

Task FR-3C. Use the findings of this study to formulate guidelines or rules for upper limits on manure spreading in feedlot regions under specified conditions.

C. Septic Systems and Groundwater

1. Task S-1

Objective: To determine the extent of groundwater contamination that exists on farms as a result of septic tank use.

Scope: The investigation will be limited to farms and will be further limited to areas representative of specified soil conditions, geology, depth of water table, climate (precipitation available to dilute the waste water) and tank design.

Approach: With data obtained from Task G-1, the following activities will be pursued:

Task S-1A. Since the density of septic tanks in farm areas is usually low (less than 10 units per square mile) the pollution potential for serious regional groundwater contamination probably does not exist, but local problems do occur. A set of areas around the country will be selected for which well test records are available. The areas are to be defined and segregated by soil types and geology. In cases where well contaminations occur at a statistically significant level, investigations will be extended to determine the pollution source. When septic sources are suspected, a study of well construction will be made and the corresponding septic tank history reviewed. Poor design of either the well casing or positioning may be more at fault than the septic tank. Conversely, the septic design and construction may be inadequate. A determination of the facets of the problem will thus be made. Areas without high water tables will not be included, but areas with fractured porous rock below a thin soil cover should be investigated, even with only moderately high water tables.

It is suggested that this study of farm septic tank pollution be made as a subset of a national study by the EPA Office of Air and Waste Management in their Solid Waste Management Program and that coordination be arranged with the R. S. Kerr Experimental Research Laboratory (Ada, Oklahoma), where a long term septic tank study is already underway.

It is anticipated from preliminary reviews that farm septic systems are an insignificant source of groundwater pollution, except on a local basis, in relation to the other sources of potential groundwater pollution from agriculture practices. Septic systems are too sparsely situated in a farm setting to be a major source of nitrate contamination of groundwater.

The only farming areas where a potential for widespread groundwater contamination may exist is where a farm or ranch supplies a concentrated area of housing for ranch and farm hands, and septic systems process the human wastes. This also applies to areas where migrant worker camps service substantial numbers of people in concentrated pockets of farmland.

## IV. PESTICIDES

### A. Task P-1

Objective: To determine the potential severity of toxification of groundwater that is suited to use for public drinking water supplies based on the history of past applications and the projected use of pesticides in the near future.

Scope: Since groundwater contamination by pesticides and herbicides has been reported in only a limited number of instances it will be necessary that the records of Water Resource Research Centers in each state be reviewed. Only those states and areas with intensive farming on permeable soil (sandy soil or thin permeable soil mantle over layered fractured rock, e.g., limestone,) with high water table and slow moving groundwater, need to be considered. Also, only those areas in which persistent varieties of pesticides are used would require such study.

A minimum level of CH (chlorinated hydrocarbon - a persistent class of pesticides) pesticide concentration in groundwater would be set for the investigation. Only in areas where the minimum CH levels are surpassed will records of lower levels be investigated; this is to identify trend patterns.

Approach: With data obtained from Task G-1, the following will be carried out:

Task P-1A. The task force formed to investigate this problem will review the records of CH usage in agriculture. These data have been published by and in the files of the USDA, Agricultural Experimental Stations and Agricultural Extension Services. Only those data need to be researched which lie within areas of intensive farming, very permeable soils (sand soils), high water table, and slow moving groundwater. Also, areas where the soil mantle is thin and is underlain by a fractured rock matrix, such as limestone, shale, etc. are candidate areas. The soil, geological, and hydrological data is provided by the Soil conservation Service of the USDA, U.S. Geological Survey, and state Geological Surveys. The areas to be investigated are those where a high water table is actually used for drinking water supplies.

Task P-1B. With or without a formal groundwater model, the data made available from the files of the various state agencies identified above will be used to determine the past, present and future migrations of CH residues. The future migrations will have to be (a) based on recent (last two years) application rates of CH; (b) based on the projected reduced rates because of present and pending regulations; and (c) based on possible increased applications rates if warranted.

Task P-1C. In areas where contamination of groundwater is known to exist, arrangements will be made for obtaining a new and representative set of groundwater samples using the methodology and procedures described by the Association of Official and Analytical Chemists (AOAC).

# V. ECONOMIC IMPACT OF MEASURES TAKEN TO REMEDY GROUNDWATER CONTAMINATION

## A. Introduction and Overview

This section will present a possible approach for assessing the economic impact of the measures taken to remedy groundwater contamination problems. It consists of a flow diagram of the complete procedure, a set of three objectives and a list of specific tasks necessary to meet the objectives.

The economic impact portion of the plan of work would be undertaken whenever a groundwater contamination problem is discovered and defined. It would begin immediately after standards, guidelines or other remedies had been established to guarantee the future purity or safety of the groundwater; the benefits* of these remedies are expected to exceed the costs of enacting them. The economic impact analysis would determine the costs of the abatement more precisely and would allow a second posteriori assessment of the benefit assumption.

The economic impact analysis will concentrate on the primary cost impacts and on the significant secondary impacts** associated with the abatement of groundwater contamination. Primary impacts are changes in the output, costs or returns of firms or individuals whose operations would be directly affected by the standards, guidelines or remedies. Secondary impacts are the changes in prices, costs or quantities of goods occurring in the support industries, competing industries or at the retail level. An example of a support industry is the fertilizer industry. An example of a competing industry is the grassfed beef industry which would probably feel the impact of any feedlot regulations. Of course, we are all affected by higher retail prices and by shortages.

*These benefits are primarily increases in the safety and health of current and future generations of human beings, of other animals, and of plants.

**It should be noted that not all secondary impacts are costs. An increase in the cost to one firm or an industry may benefit a competing firm or industry.

The procedure to be used in the economic impact analysis can be structured according to three main objectives. These are: (a) to choose the best set of possible alternative remedies to groundwater problems, (b) to determine the primary impacts of these alternative remedies on a firm, industry and regional basis, and (c) to identify and assess the significant secondary impacts of the most promising remedies. Inferior remedies will be discarded at the completion of each phase of the analysis. This will keep the procedure efficient. On the other hand, the effort made to explore alternative methods of abatement under the first objective will help insure that the most rational remedies are subjected to the impact analysis.

The three objectives are represented in the flow chart of the procedure (Figure 2-V-1) as three columns. In the lefthand column are the tasks to be performed in choosing the best abatement methods. As can be noted from the diagram, either a task-force approach or a Delphi technique can be used to complete this objective. In the middle column, the tasks necessary to assess the primary impacts are shown. Firm-level output and cost impacts would be determined while meeting the initial objective; hence, the tasks needed to complete the second objective are mostly concerned with aggregation to the industry and regional levels. The right-hand column and the third objective are concerned with delineating the major secondary impacts. Tasks required to fulfill this final objective are identification of impacts important enough to be analyzed; choice of analytical technique to use in the analysis; and performance of the analysis itself.

Two other aspects of the flow-charted procedure should be noted. An option to bypass Objective 1 is included to account for a situation where the standard, guideline or remedy is already known and/or specified by law. This option is not under any of the three objectives. Also noteworthy is the branch in the left-hand column which indicates that if a byproduct can be found from an abatement remedy which will pay for the remedy, then no further study of impacts is needed. An example of the first option might be a pesticide groundwater pollutant for which there is a substitute pesticide. Objective 1 can be bypassed if there is confidence that the one pesticide will be substituted for the other. An example of the second option would be a manure byproduct that makes it feasible to capture the liquid and solid wastes before they penetrate the soil surface.

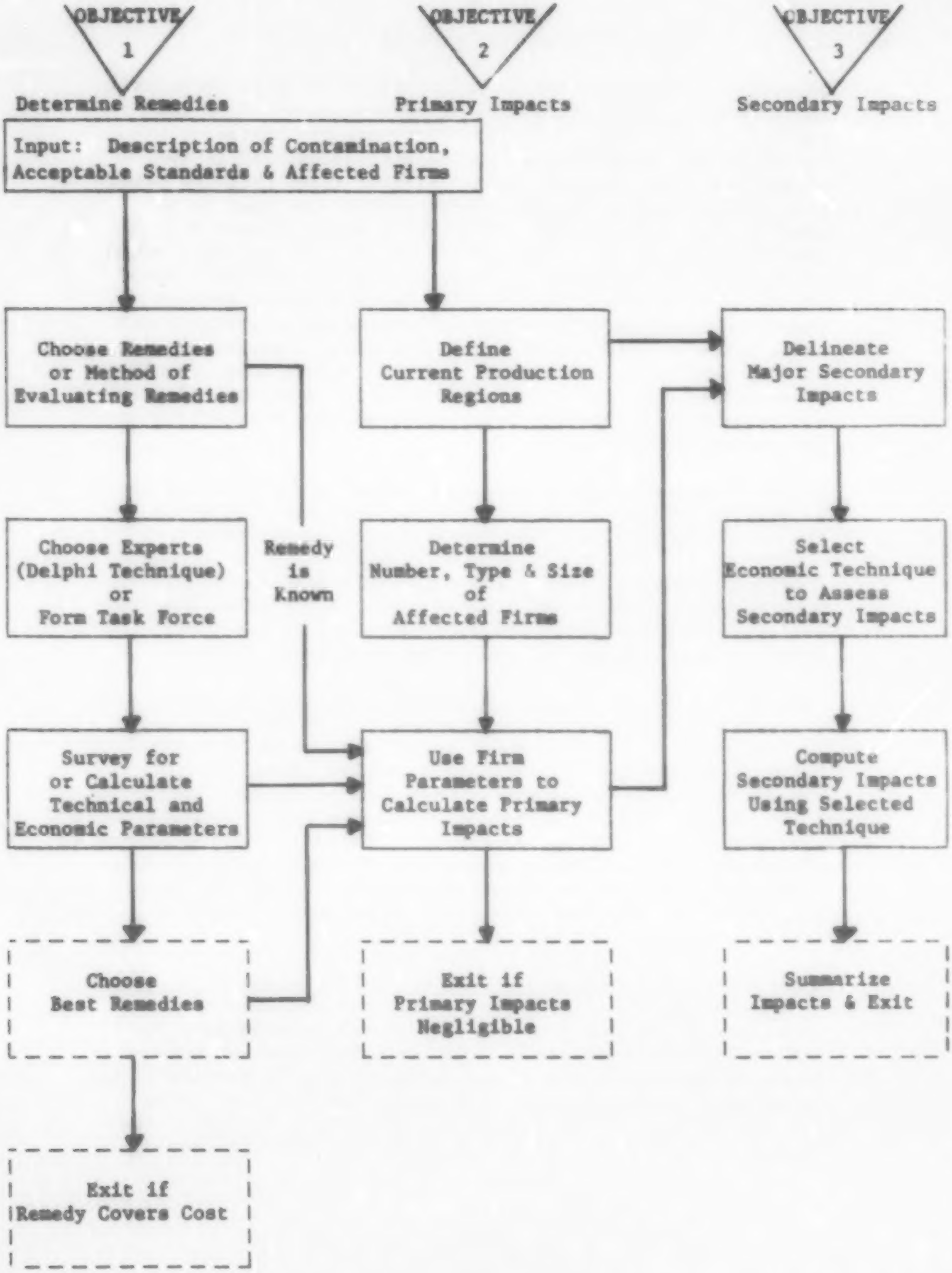
OBJECTIVE 1
Determine Remedies
OBJECTIVE 2
Primary Impacts
OBJECTIVE 3
Secondary Impacts
Input: Description of Contamination, Acceptable Standards & Affected Firms
Choose Remedies or Method of Evaluating Remedies
Define Current Production Regions
Delineate Major Secondary Impacts
Choose Experts (Delphi Technique) or Form Task Force
Remedy is Known
Determine Number, Type & Size of Affected Firms
Select Economic Technique to Assess Secondary Impacts
Survey for or Calculate Technical and Economic Parameters
Use Firm Parameters to Calculate Primary Impacts
Compute Secondary Impacts Using Selected Technique
Choose Best Remedies
Exit if Primary Impacts Negligible
Summarize Impacts & Exit
Exit if Remedy Covers Cost

Figure 2-V-1 Flow Diagram of Economic Impact Analysis

## B. Task E-1: Choose Alternative Remedies

Objective: The goal here is to determine the most technically and economically feasible ways of abating groundwater contamination. In many cases, the most feasible abatement alternative may be well known and/or well documented in the literature. For example, it may be well known that one pesticide will readily substitute for another and that this substitution will relieve the need for major changes in current agricultural production practices. Objective 1 would be bypassed in this case. A case in which Objective 1 would not be bypassed might be a feedlot waste disposal problem where the remedies could range from building an effluent and solid waste holding system to manufacturing a byproduct such as composted manure or methane gas. In such a case, feasible alternatives have to be defined and their technical and economic parameters determined before the remedies most likely to be used can be chosen.

Scope: Limited to those specific contamination problems where several attractive abatement alternatives exist and where choice of the most feasible remedy is not easily made.

Approach: Either a Delphi procedure or a Task Force approach will be used. The Delphi approach will be preferred for the easier choice problems. The more complicated Task Force approach would be used if the choice problem is difficult.

Task E-1A. Choose analytical method to be used in determining most feasible contamination remedies. To do this, one would (a) assemble information about scope, seriousness and attributes of groundwater contamination problem (from earlier phases in project), (b) gather what easilyobtainable information about possible abatement procedures exists, and (c) in conference with EPA representatives, choose either the Delphi technique, the Task Force approach or the most likely remedy(ies). If a remedy, or a set of remedies, is chosen during completion of this task, the other tasks under Objective 1 would be omitted.

Task E-1B. Choose experts to be polled in Delphi technique or choose members of task force. Experts for the Delphi procedure would come from both inside and outside government and would be knowledgeable about both the technical and the business aspects of the agricultural firms contributing to the groundwater contamination. The group should include some representatives of the firms which would be affected by the abatement practices. If a task force is formed it should include Agricultural Scientists (who would know about plant varieties, row spacings, cultivation practices, etc.), Agricultural and/or Civil Engineers (who would know equipment and processes), and Agricultural Economists (who would know markets and comparative costing techniques). Such a task force could use a systems approach in studying the alternative abatement possibilities. The credibility of this approach is attested to by such successes as the development of mechanical harvesting for tomatoes.

Task E-1C. Perform analyses needed to make choice of abatement alternatives and calculate cost and returns of each alternative remedy. These analyses need to generate two kinds of information: technical parameters and economic parameters. In the final rounds of the Delphi procedure, if it were used, experts would be polled about such items as fertilizer application rates, recommended varieties, sizes of holding ponds, equipment needed for methane gas production, costs of application, equipment, etc. and prices of composted manure, etc. These questions would be formulated for only a few of the most promising remedies and only near the completion of the Delphi procedure; otherwise, the response rate of the experts will be inadequate. If a task force approach is used, the member of the force who has the relevant expertise will take final responsibility for providing each relevant parameter. Since cost and price parameters are included, one output of this task will be the direct impacts of the pollution abatement on the affected firms. If this task is not performed, the direct economic impacts of the known remedy would be calculated as part of Task E-2C.

Final Note: A task Force analysis might turn up a byproduct process which will abate the groundwater pollution and pay for itself while doing so. Objectives 2 and 3 would be omitted in this case as additional cost impacts would be well outweighed by the benefits accruing from the pollution abatement.

## C. Task E-2: Determine Primary Industry Effects

Objective: Cost and/or output impacts on the industries containing the polluting firms are to be determined during the completion of this objective. Also, if the cost impacts directly associated with polluting firms were not calculated under Objective 1, they will be determined here. Industry impacts are of critical importance in order to assess the national and international trade effects of the abatement remedies. If these are negligible, costs of abatement will be borne primarily by the polluters. If they are significant, abatement will also include social costs. Since these costs may vary by region, a regional stratification will be made. If primary impacts at the industry level are negligible, Objective 3 can be omitted.

Scope: Attention will be focused only on U.S. agricultural production industries directly affected by corrective action. The impacts of remedial action upon supportive and competitive industries or on final consumers will be determined in Objective 3.

Approach: The impact of corrective action will be determined via collection and revision of existing USDA and Bureau of the Census data.

Task E-2A. Define Current Production Regions. Efforts to determine the regional distribution of production should be closely coordinated with executors of the technical and engineering phases of the total analysis. It will be necessary to arrive jointly at relevant regional definitions. Soil types, and location of major market areas and supportive industries should be considered. Regional delineation is of critical importance because the imposition of corrective measures could alter significantly the nature of competition that exists between major production areas.

Task E-2B. Determine number and size distribution of firms affected in each region. It is possible that remedial action will affect only small firms in one region. If the region is characterized by a wide range of firm sizes, the effects of corrective action in all probability will be small. However, if the instituted action affects a large firm which accounts for a large share of regional and national output, the economic impact could be rather significant. Therefore, to arrive at a realistic assessment of the primary effects it will be necessary to consult USDA and Bureau of the Census data. These data and associated studies will be used to derive size distributions of firms by region.

Task E-2C. Use firm parameters to calculate total impact on industry by region. Given the isolation of areas where corrective action is necessary (output technical and engineering phase) and firm parameters developed under Objective 1 of the economic impact analysis, the total impact on the industry will be calculated by region. Changes in firm cost structure reported under Objective 1 will be translated into industry and regional price and quantity changes. If the cost impacts on the affected firms have not been calculated previously, they will be computed as part of this task. Partial budgeting procedures will be used to carry out this computation.

## D. Task E-3. Determine Secondary Effects

Objective: The purpose of this objective is the quantification of the effects remedial action has on supportive and competitive industries. Demand for outputs and/or services rendered by industries serving in support roles, such as the feed grain industry in the case of feedlots, could be severely altered by the institution of corrective measures. Competing industries, such as the grass-fed beef industry once again in the case of feedlots, may find the demand for their products increased as a result of government intervention. An additional possible outgrowth of the correction of spillover activities is the increase in prices at the consumer level. The nature of the effect on consumers, as well as the previously mentioned secondary impacts, will be derived using the results generated under Objectives 1 and 2.

Scope: The analysis will be limited only to supportive and comparative industries indicated to be affected by results derived under Objectives 1 and 2. Consumer impacts will be determined only in situations where significant price changes are indicated.

Approach: Examination of results of tasks accomplished under Objectives 1 and 2 to determine impact areas. Select appropriate economic tools and execute the analysis.

Task E-3A. Delineate major impacts which should be studied. Assessment of secondary impacts will require identification of affected supportive and competitive industries. Findings under Objectives 1 and 2 will set the initial boundaries. For example, evidence discovered in the execution of tasks contained in Objective 2 may indicate a decrease in the demand for feed grains as a result of feedlot regulation. Given this information, the analysis can proceed to the determination of the feedgrains affected. Results obtained under Objectives 1 and 2 will be used also in the assessment of the effects remedial action will have upon consumers.

Task E-3B. Selection of Economic Tools. Several possible economic tools are available which can be used to perform an impact analysis. Budgeting aggregation, commodity section models, input-output analysis, and economic base analysis are examples of possible techniques which could be used to determine the impact of remedial action on supportive and competitive industries.

The final decision as to the technique used will be based on output generated under Objectives 1 and 2, in consultation with informed industry, EPA representatives and other qualified sources. Consumer impacts will be derived via the use of the price elasticity of transmission and Griliches' social welfare approach.

Task E-3C. Execution of Analysis. Once the boundaries for the analysis have been established and tools selected, it will be necessary only to collect the relevant data and to locate the necessary parameters and proceed with the chosen analytical procedure.

## VI. MODELING

### A. Task M-1

Objective: The objectives of modeling a particular situation such as the intrusion of toxic substances into groundwater recharge, whether from nitrates or pesticides, is to be able to predict on a fairly reliable basis what the future consequences will be with continued use of these substances. Modeling should also permit us to vary certain parameters so as to determine the application level at which the substance would no longer toxify the groundwater. It is desired that modeling be capable of dealing with large land areas in order to describe adequately the expected effect on an aquifer for several years in advance.

Scope: At present the state-of-the-art in groundwater modeling does not permit the modeling of large areas. It will be necessary therefore to determine the extent to which various existing models can be adapted to this purpose, and the degree of reliable prediction to be expected and the number of input parameters required. The task will be to select a model or to adapt a set of models and suitable submodels which can fulfill the objective of this program. Modeling of a sophisticated nature is not warranted for areas showing small changes of nitrate in groundwater over a period of a decade or more since fertilizer and animal waste applications obviously do not add significantly to these groundwater contaminations.

Approach: The objectives of the program will be reached by the accomplishment of the following tasks:

Task M-1A. During June of 1975 the EPA awarded a contract to the Commission on Stimulation Modeling of the Scientific Committee on Problems of the Environment to evaluate the existing groundwater basin management models (EPA project control number R803713-01). A liaison with this committee should be established by the EPA groups concerned with modeling the effects of fertilizers, pesticides, feedlots, and septic tanks on groundwater recharge. Even though the committee's work is scheduled for completion in July 1976, the modeling groups will receive invaluable benefit from the collected ideas and will also be able to share their insights.

Among the above group of individuals interacting with the Committee the EPA should assign a team of persons who will be responsible for developing a groundwater model.

Task M-1B. (a) Using the findings of the Scientific Committee on Problems of the Environment, a modeling effort for fertilizers can develop a non-point source model to predict the quantity of groundwater which will be toxified by applications of fertilizer under various assumptions. The initial phase of this Task will be to develop a working model which will predict the effects on groundwater from various levels of fertilizer applications versus suitable parameters within a watershed or basin. This will be utilized to determine the time period in which toxification will occur (if indeed it will). It will also be an aid to agricultural extension services around the country in recommending fertilizer application rates so as to protect groundwater recharge.

Task M-1B would be designed to model a watershed or basin using available data from well tests. The well data will have to span at least a decade or more and be correlated to fertilizer application levels (along with crop practices, climatology, hydrology, etc.) of the affected area. The modeling effort will be designed to produce a simplified model which will take into consideration the change in fertilizer application patterns over the years and relate them to the changes in the nitrate levels in the groundwater (as recorded from well test sample taken over the last decade). Once an historical pattern is determined, fertilizer application levels should be simulated which show how the groundwater nitrate level can be influenced by fertilizing at versus other relevent factors including changes of crop or tillage practices.

The data for Task M-1B will be supplied through the efforts of the Fertilizer Task group determining the extent of nitrate toxification of groundwater as resulting from fertilizer usage. (b) Part 2 of Task M-1B is the same as Part 1, except that it would be applied to pesticides using data supplied by the Pesticide Task group.

Task M-1C. In that the EPA, Athens, Georgia, laboratory is already concerned with modeling the effects of pesticide in sub-surface and surface run-off situations, and are funding an approximately 20 square mile test area to calibrate the model, it would be reasonable to extend the program by means of additional funding to include the effects of pesticides on underground recharge areas in addition to those of subsurface run-off aquifers, (i.e., those aquifers which intersect a surface water body such as a river or lake.) Only a modest increment in funds would be required to develop a subprogram to handle the case in hand.

Task M-1C would be a more detailed effort that Task M-1B and would demand more specific data to be taken and cover a less extensive area than Task M-1C.

Task M-1D. An effort to model point sources of nitrate intrusion into soils, (i.e., from feedlots, barnyards, dairy cow milking areas, poultry houses, and septic tank operation) should be attempted using models developed by ERDA, which already account for various ground factors and chemical changes. This modeling group can be the same group as described in Modeling Task M-1B; if a different group, it should operate in a manner similar to that of modeling Task M-1B. The model should include operation of the point source during the start-up period, normal operation period, and phase-out period. The model should predict what limits are to be set on size, distance from the aquifer and/or wells, and the conditions of operation of the point source, in order to preserve the quality of the underground waters.

Note on Modeling Task: Modeling is not a problem in itself but a tool for analysis. The sophistication of the model should be of the same order of magnitude as the precision of the data which will be available as input to the model.

# THE IMPACT OF INTENSIVE APPLICATION OF PESTICIDES AND FERTILIZERS ON UNDERGROUND WATER RECHARGE AREAS WHICH MAY CONTRIBUTE TO DRINKING WATER SUPPLIES

## Section 3

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